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SCIENCE AND THE MECHANIC ARTS

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THE AUDION—ITS ACTION AND SOME RECENT APPLICATIONS.*

BY

LEE DE FOREST, Ph.D., Sc.D.

ANALOGIES are apt to be interesting, and in scientific matters frequently instructive and clarifying. The title of to-night's paper, "The Audion," suggestive of *Sound,* prompts the consideration of an analogy in the realm of *Sight*—the microscope. The audion, in a measure, is to the sense of sound what the microscope is to that of sight. But it is more than a magnifier of minute sounds, electrically translated; the audion magnifies and translates into sensation electric energies whose very existence as well as form and frequency, would but for it remain utterly unknown. As the microscope has opened to man new worlds of revelation, studies of structure and life manifestations of natural processes and chemical reactions whose knowledge has proven of inestimable value through the past three generations, so the audion, like the lens exploring a region of electro-magnetic vibrations but of a very different order of wave-length, has during the scant thirteen years of its history opened fields of research, wrought lines of useful achievement, which may not un-

* Presented at a joint meeting of the Section of Physics and Chemistry and the Philadelphia Section, American Institute of Electrical Engineers, held Thursday, January 15, 1920.

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fairly be compared with the benefits from that older prototype and magnifier of light waves. But when the first steps were taken in the work, which eventually resulted in the audion of to-day, I no more foresaw the future possibilities than did the ancient who first observed magnification through a drop of water realize the present application of the high-power microscope to bacteriology.

In 1900, while experimenting with an electrolytic detector for wireless signals, it was my luck to be working by the light of a Welsbach burner. That light dimmed and brightened again as my little spark transmitter was operated. The elation over this startling discovery outlasted my disappointment when I proved that the unusual effect observed was merely acoustic and not electric. The illusion had served its purpose. I had become convinced that in gases enveloping an incandescent electrode resided latent forces, or unrealized phenomena, which could be utilized in a detector of hertzien oscillations far more delicate and sensative than any known form of detecting device.

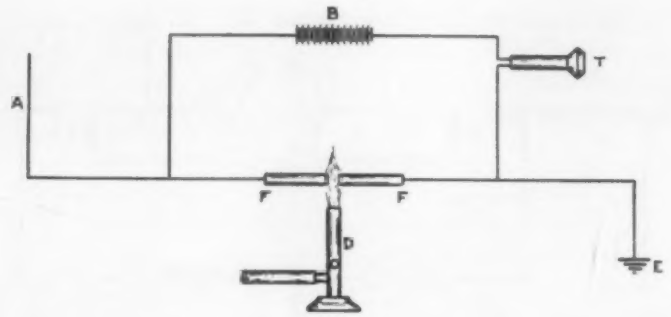
The first "commercial" audion, as it originally appeared in 1906, was therefore no accident, or sudden inspiration. For failing to find in an incandescent mantel the genuine effect of response to electrical vibrations I next explored the bunsen burner flame, using two platinum electrodes held close together in the flame, with an outside circuit containing a battery of some 18 volts and a telephone receiver. See Fig. 1—the form used in 1903. Now when one electrode was connected to the upright antenna and the other to the earth, I was able to clearly hear in the telephone receiver the signals from a distant wireless telegraph transmitter. The resistance of this new "flame detector" was decreased when the flame was enriched by a salt. Next the incandescent gases of an electric arc were considered; and likewise the action in the more attenuated gases of an ordinary lamp bulb, surrounding an incandescent filament or filaments.

But during these early years I was afforded little time to concentrate on this laboratory problem, and it was not until 1905 that I had opportunity and facilities for putting to actual proof my conviction that the same detector action which had been found in the neighborhood of an incandescent platinum wire, or carbon filament, in a gas flame existed also in the more attenuated gas surrounding the filament of an incandescent lamp. In

one case the burning gases heated the electrodes; in the other the electrodes heated the remanant gases. But in both it was *first* the electrons from the hot electrodes, and *second* ionization of the gases which these electrons produced, which established an electrically conducting state, extraordinarily sensitive to any sudden change in electrical potential produced on the electrodes from some outside source.

Considering therefore this actual genesis of the audion it will be seen that it was never, strictly speaking, a *rectifying* device. True both electrodes were seldom alike and a " polarization " was always had from the outside battery, but any rectification of the alternating currents impressed on the detector was merely inci-

FIG. 1.

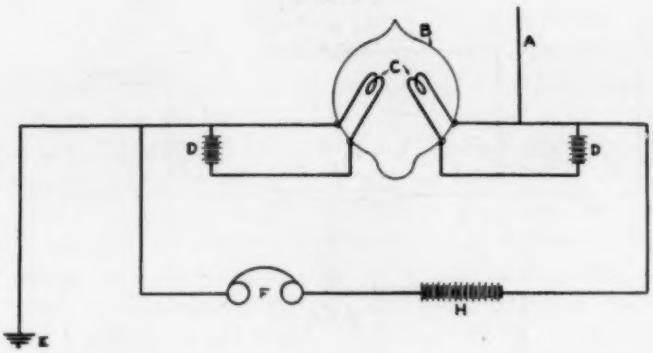


dental and played no vital part in the action of the audion. From the beginning I was obsessed with the idea of finding a *relay* detector, in which local electric energy should be controlled by the incoming waves–and not a mere manifestation of the electrical energy of the waves itself. Hence it was that the external battery as a source of local energy was always employed, when the incandescent filament was utilized as source of the electric carriers through the gas. The battery for lighting the filament I was styled the "A" battery and, as distinguished from this, the other battery was named the "B" battery. This nomenclature has been retained, and is to-day commonly accepted, even by the many who for various reasons refuse to recognize the name " audion."

At the period now under consideration, 1903–05, I was familiar with the Edison effect and with many of the investiga-

tions thereof carried on by scientists, Prof. Fleming among others. In 1904 I had outlined a plan of using a gas heated by an incandescent carbon filament in a partially exhausted gas vessel as a wireless detector, in place of the open flame. But here the rectification effect between hot filament and a cold electrode was not considered. Two filaments, heated from separate batteries would give the desired detector effect equally well. What I had already found in the flame detector, and now sought in a more stable and practical form, was a constant passage of electric carriers in a medium of extraordinary sensitiveness, or tenuity, which carriers could be in any conceivable manner affected to a marked degree by exceedingly weak electrical

FIG. 2.



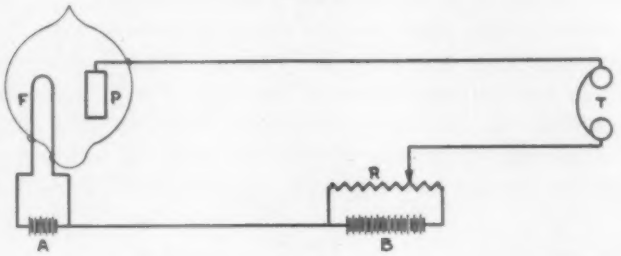
impulses, delivered to the medium, indirectly or through the hot electrodes. Fig. 2.

The ordinary small incandescent lamp of that epoch supplied admirably the conditions I required, merely by the introduction of a second electrode. That added electrode could be either hot or cold. Obviously therefore, use it cold, avoiding thus the unnecessary battery. Then obviously, too, I must so connect my telephone "B" battery as to make this cold electrode positive, for otherwise no local current could flow through the gaseous space in the lamp between the unlike electrodes. Fig. 3.

The high frequency impulses to be detected were, as in the earlier flame type, originally applied directly to these same two electrodes. That these alternating electric currents were thereby rectified was merely incidental. A glance at the plate-current, plate-voltage curve (Fig. 4), shows why, even were both anode

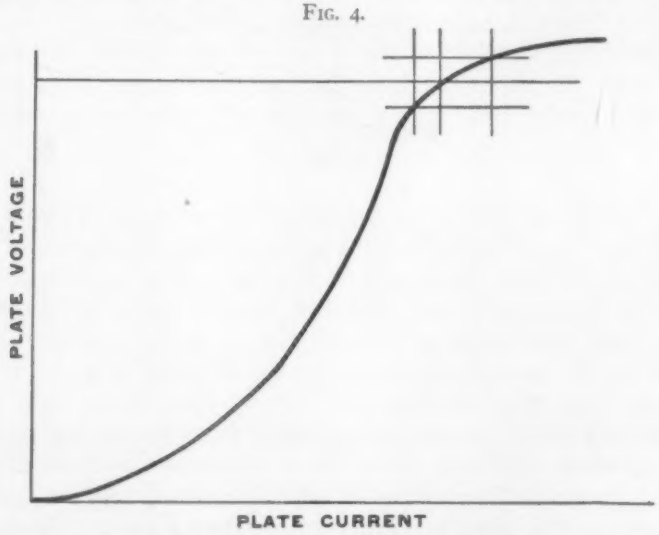
and cathode hot, the receipt of a train of high-frequency current waves would produce a resultant change in the normal telephone current and result in a signal. This typical curve, taken from a "gasey" lamp, such as I first employed, is curvilinear over two

FIG. 3.



portions. If now the "B" battery potential was so adjusted that the detector was operating on either knee of this curve the increase to this locally applied voltage, resulting from the positive halves of the wave-train, would produce a greater (or less)

FIG. 4.



increase in the local current flowing across the gap than would the negative halves of the wave-train produce a decrease (or increase, as the case might be).

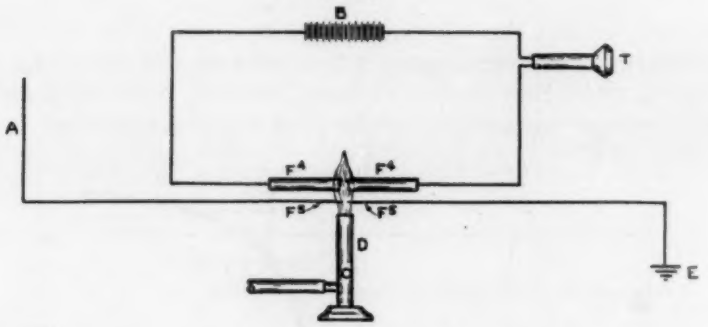
In other words, the responsive action of this two-electrode

audion was due to the asymmetry of its characteristic curve, rather than to its rectifying property. This latter property could be made to aid, to increase the intensity of the signal produced originally and mainly by the so-called "trigger," or genuine *relay* action of the device, which was always *controlling* the local energy by means of a much smaller income energy.

In others words, then, the two-electrode audion, with A and B batteries, was not primarily a "valve." And I have always objected to this misapplication of the name *valve* to the audion; a name which our British friends have from the first persisted, with a stubbornness worthy of a better cause, in misapplying!

Long before the two-electrode relay audion of 1905 had a

FIG. 5.



chance to prove its worth in commercial wireless service I had found that the influence of the high-frequency impulses could be impressed to better advantage on the conducting medium from a third electrode. In its first inception the third electrode also dates back to the flame detector of 1903. Fig. 5, taken from the earliest patent of the audion group, shows the original idea of keeping the high-frequency current path distinct from that of the local telephone current. Consequently when in 1906, having secured the maximum efficiency from the two-electrode vacuum type, I cast about for further means of improvement, it was but natural to revert to this plan of separating the two circuits. The new electrode connected to the high-frequency secondary circuit was at first applied to the outside of the cylindrical lamp vessel; the other terminal of the secondary circuit was led to one terminal of the lamp filament. Fig. 6, of a 1906 patent, shows this pro-

genitor of the third electrode. This simple arrangement proving a step in advance, I concluded that if this auxiliary electrode were placed within the lamp the weak charges thereto applied would be yet more effective in controlling the electron-ionic current passing between the filament and plate.

FIG. 6.

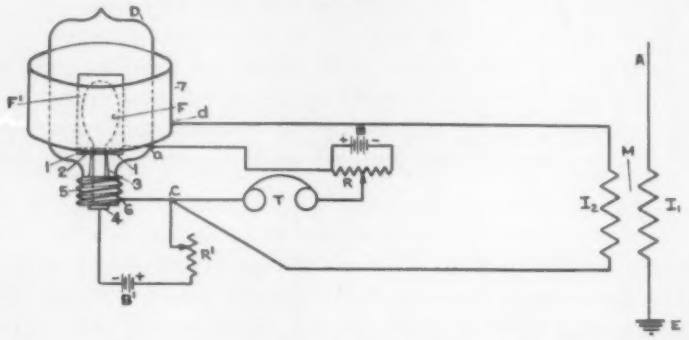
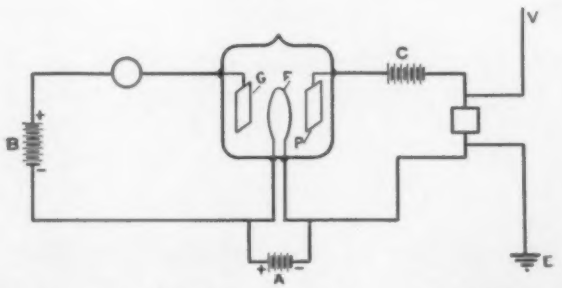


Fig. 7, taken from a patent filed two months after the preceding one, illustrates the next arrangement tried. Here I used two plates, one either side of the filament—one in the telephone circuit, the other in the high-frequency circuit associated with the antenna. It will be noted also that here for

FIG. 7.

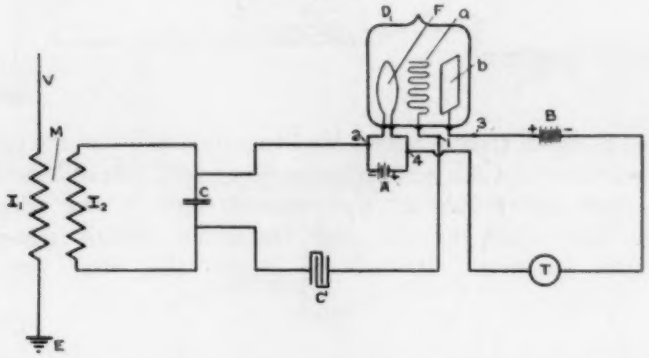


the first time was shown the third, or "C" battery, in the input circuit, so much employed of late, notably when the audion is used as amplifier of telephonic currents. This two-plate device proved another decided step forward, and I realized then that if this third electrode were placed directly in the path of the carriers between the filament and plate anode I would obtain the

maximum effect of the incoming impulses upon the local current flow. But obviously another electrode thus placed directly in the stream must not be a plate—it must be perforated to permit the carriers to reach the anode. A wire bent back and forth in form of a grid should answer admirably. Fig. 8, taken from the patent filed in January, 1907, the so-called "Grid Audion" patent, illustrates the preferred form which the idea promptly assumed.

In surveying the wide field of electric communication to-day one cannot look back at that little figure, of the first grid electrode, without a sense of wonder at the enormous changes which it has wrought. It has made possible *commercial* trans-oceanic radio telegraphy. It has realized trans-Continental telephony:

FIG. 8.



it has made reception of wireless signals half-way around the globe an everyday occurrence. The uncanny accuracy of millions of shells from the Allies' guns, the clock-like precision of advancing barrages, would have been impossible save for the effectiveness of their trench and airplane radio service, in which the grid audion was the essential heart. To-day this little grid controls and modulates an ever increasing kilowattage of radio telephone energy, which as early as 1915 conveyed the spoken voice from Arlington to Honolulu, and more recently from New Brunswick to the transport *George Washington*, in the harbor of Brest. It has already placed twenty simultaneous telephone messages upon a single pair of wires. A few ounces of grid wire make possible the saving of hundreds of tons of copper in long distance telephone conductors. It has given to the physicist

a tool for the exploration of unprobed fields of research; and to the electrical engineer a generator, without moving parts, of alternating currents of any desired frequency, from one to ten million period per second—a machine absolutely constant and reliable in its silent work.

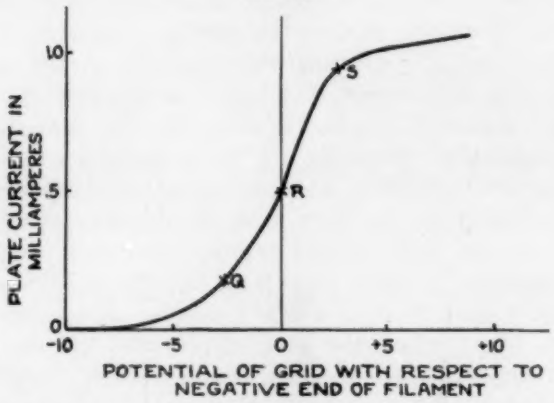
Let us consider briefly the explanation of all this radical advance, the theory of the invisible mechanism whereby this astonishing control of powerful energies by minute impulses is effected. Lacking a very concrete conception of just what electrons are and just how electric charges residing on a grid can so effectively dam back the flood of electrons expelled at enormous velocities from a hot cathode at the urge of high potentials—our minds must be content with pictures of characteristic curves and mathematical formulæ, at best but crudely interpretive.

The fundamental operating characteristic of the audion is that expressing the current flowing from filament to plate in terms of the potentials supplied to the grid. Fig. 9 expresses this relation graphically. Here we see that a moderate negative potential (10 volts) applied to the grid completely cuts off the current between filament and plate. As this negative grid charge is reduced to *O* the plate current rapidly increases. As the grid potential becomes positive this plate current continues to increase up to a point *S*, after which it rapidly approaches a saturation value, above which the plate current will not rise, regardless of how high is the positive potential applied to the grid. This curve was taken with a given fixed potential difference applied between filament and plate, and for a given filament temperature. This sample characteristic was taken from a "hard" audion, from which the gas has been sufficiently well exhausted to show no irregularity in its curve, due to ionization. It will be observed that over the straight line portion of this curve, between points *Q* and *S*, when the grid potential varies a small but equal amount on right and left of zero, the amplitude of variation in the plate current is directly dependent on the variation of the applied grid potential. In other words, there will be over this range no distortion between the wave form of the incoming alternating potential impressed on the grid and that of the current fluctuations produced in the plate, or output, circuit. Obviously therefore the straight line portion of the audion characteristic is the one to utilize in an audion amplifier, or repeater.

whether for amplifying radio or voice-frequency currents. Consequently we find telephone engineers going to extreme lengths to so design their audions and circuits, and to so regulate the potentials applied to the grid, as to operate entirely within this straight line characteristic. The result is a perfect reproduction of voice currents, but magnified to any extent desired by the use of two or more such amplifiers connected in cascade—from ten to twenty thousand times or more.

But when the audion is used as a simple detector of damped radio signals, where it is desired to obtain the maximum possible integrated effect from a train of incoming high-frequency waves

FIG. 9.



upon the direct current in the plate circuit, it is desirable to operate at the lower, or upper, knee of this characteristic curve, for the reason already explained. Here we have taken advantage of the asymmetry of the curve, so that the sum of the decreases in the plate current as the grid potentials decrease, greatly outvalues the sum of the increases in the plate current, when the grid potentials increase. This results in an integrated decrease in the current through the telephone receiver, which may represent much greater energy than that of the incoming wave-train.[1] It is thus that the audion can operate as a true *relay* device, possessing a sensitiveness far greater than that of the most perfect crystal rectifier, or of any valve. Consideration of the advan-

[1] Where a "C" battery is employed for keeping the grid always negative, the audion is operated on the lower knee of its characteristic curve.

tage of thus working on the asymmetric portion of the audion curve would lead us to expect an increase in sensitiveness as a detector of spark signals if this asymmetry be further emphasized by the introduction of a small amount of gas into the bulb, thus producing a very appreciable amount of ionization. Such has long been known to be a fact—no high vacuum audion to-day equals, as a radio detector, the "soft" bulbs which were in very general use a few years ago. The presence of such an amount of gas is usually evidenced by a blue haze seen around the anode, when high potentials (say from 60 to 100 volts) are applied across plate and filament. Ionization phenomena always introduce certain irregularities in the operation of the audion, and kinks, or cusps, in its characteristic curves—even where the gas pressure does not greatly exceed one-ten-thousandth of a millimetre of mercury.

Our knowledge of electrons is of comparatively recent date. In 1899 J. J. Thompson showed that negative electricity is given off from a heated carbon filament in the form of electrons having a mass of 1/1800 that of a hydrogen atom. These electrons may be considered as atoms of electricity. Richardson, in 1903, first applied the electron theory of metallic conduction to emission from heated conductors. He assumed that electrons are ordinarily held bound within the metal by an electric force at the surface, by a tension similar to the surface tension of liquids. But if the velocity of an electron be made sufficiently high, as by applied heat, it is able to overcome this surface force and escape. The number of electrons, therefore, which attain the necessary critical velocity to escape will increase very rapidly with the temperature. The laws are similar to those governing the increase in vapor tension of a liquid with increasing temperature. Richardson thus concluded that the electronic emission from an incandescent metal should increase according to a similar equation:

$$i = a\sqrt{T}\, e^{\frac{-k}{T}}$$

where i is the current per square centimetre at temperature T, and k is a constant dependent on the latent heat of evaporation of the electrons. But actual investigations of the Richardson law, notably by Dr. Langmuir, showed that as the heat of a cathode filament was increased the thermionic current increased first in accord with Richardson's equation, but that beyond a certain

point further increase in temperature produced no further increase in thermionic current.

A family of saturation curves, each one corresponding to a certain applied fixed potential between cathode and anode, results, as shown in Fig. 10, where the first parts of the several curves combine to form a single curve following Richardson's law. These curves [2] show that the thermionic current does not continue to increase as expected, because the space surrounding the hot filament is capable of carrying only a certain current for a given potential difference. The explanation offered is that the electrons surrounding the filament soon set up a "space charge" which repels new electrons escaping from the filament, causing some to return to the filament.

From a study of the curve family of Fig. 10, Langmuir has evolved a formula introducing the factor of plate potential, in the case of a filament coaxial with a cylindrical anode. Here the current in amperes

$$i = 14.65 \times 10^{-6} \cdot \frac{V^{\frac{3}{2}}}{r}$$

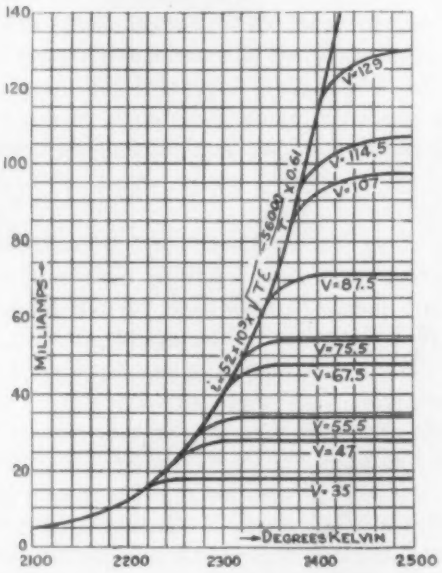
where r is the radius of the cylinder in centimetres. But extremely minute amounts of gas vitiate the correctness of this formula by neutralizing more or less the space charge.

Therefore for a power oscillator a certain definite amount of gas in the tube may prove a distinct advantage. The filament, if of tungsten, has a tending to absorb gas, so that if a small amount only is left in the tube on exhaustion the audion shows a tendency to grow "harder" with use. A perfect vacuum is never attained; spectrum analysis shows traces of residual gases always present, even in the "hardest" of tubes. If powerful bombardment of anode plates is long continued, gases will be thereby driven out from the metal and the tube rapidly become too soft to be of use—unless the gases have first been thoroughly exhausted from all metal parts within the oscillion, by methods well known to the X-ray tube art. Moreover, too much positive ionization tends to disintegrate the cathode filament. With negligible ionization there appears to be no disintegration of the filament by the electronic discharge, and its life is as great as though no electronic current flowed.

[2] Due to Dr. Langmuir.

We have just seen, then, how the space charge surrounding a hot cathode can, in the absence of sufficient ionization, produce a saturated condition of the plate current. This current, or number of electrons emitted, is fixed by the cathode temperature for a given applied voltage, while the velocity of the electrons is dependent on this applied voltage. These electrons, escaping from the cathode and producing the choking space charge, can equally well charge up a third electrode located in this space to a

FIG. 10.



considerable negative potential with respect to the cathode. It will be seen therefore how readily one can expect to control the plate current by means of relatively small potentials, positive or negative, applied to this control electrode, the grid. But the presence of the grid between cathode and anode so complicates the electric field distribution that a theoretical analysis of the relation between the plate current and the plate voltage and the grid voltage (with respect to the filament) is too complicated to be of any practical use. Empirical formula for predetermining the characteristics of various types of audion have been evolved. These, unlike the greater mass of mathematical writings already

flooding this new art, are actually proving of some real help to the tube engineer.

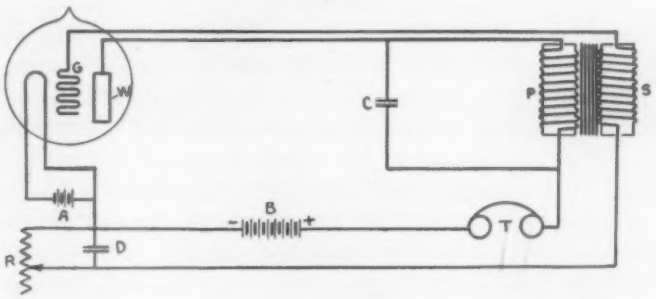
In a highly exhausted bulb the so-called " space charge " ordinarily acts to very quickly limit the thermionic current flowing from the hot cathode to the cold anode, but the present of positive ions partly neutralizes this space charge. Now if a small positive charge be applied to the grid the velocity of the electrons passing through it is increased, and consequently they produce more ions by bombardment. Moreover, the number of electrons passing the grid is increased, which in turn again increases the ionization. If too much gas is present, permitting too large a plate current to flow, the relaying action of the audion disappears, because the grid charges are then unable to control the large ionic currents. This condition is usually evidenced by the visible blue glow. In the region between these two limits the audion may possess an extraordinary sensitiveness, as is usual with any condition of instability.

In the early days when audions were exhausted, like the ordinary incandescent lamp, by oil pumps merely, it was ordinarily impracticable to exhaust to such high vacuua as to permit the use of more than 40 to 80 volts of B potential, without producing this excessive ionization. However, in 1912, when I first began to construct larger bulbs for large amplification of telephonic currents, it became apparent that the higher voltage necessary for producing the loud amplifications desired required higher and higher potentials, which obviously necessitated higher vacuua, and better methods of exhaustion. It was then for the first time that I caused audion bulbs to be exhausted by X-ray tube methods, enabling me to apply several hundred volts of plate potential. So the perfecting of means for exhausting the bulb kept pace with the growing requirements for larger power to be handled. There was at no time in the evolution of the audion, from the original incandescent lamp vacuum to those high exhausts now necessary in the largest " power-tube," or oscillion, any definite demarkation in the degree of vacuum needed or obtained. The lamp-makers' and glassblowers' skill kept pace with the radio engineers' requirements of larger bulbs and greater amounts of energy handled.

In the earlier types of audion detector a stopping condenser in the grid lead was usually, but not always, employed. There were

then sufficient ions in the bulb to ordinarily prevent the gradual accumulation on the thus insulated grid of a large negative charge, which would very rapidly completely cut off the plate-filament current. However, when heavy static discharges struck the receiving antenna it was frequently observed that the audion would be "paralyzed" for several seconds thereafter. We early learned how to discharge this residual negative accumulation on the grid, at first merely by putting the wetted fingers across the grid and filament terminals. This primitive "grid leak" was soon made in permanent form—for example, a wet string, and later a high-resistance graphite pencil mark. As the degree of vacuum of the bulb was increased the necessity for this grid leak became more urgent, and since 1913 it has been generally ap-

FIG. 11.



plied to all high vacuum tubes, when stopping condensers are used; whether the bulb be a detector, amplifier, or generator of alternating currents.

It was in the summer of 1912, when at work on the problem of audion amplifiers in cascade arrangements for telephone repeaters, that I first discovered that if the input, or grid, circuit was inductively coupled with the output, or plate inductance, the audion became a generator of continuous alternating currents, originally made evident by a shrill tone in the telephone receiver. A typical regenerative circuit is illustrated in Fig. 11. The explanation of the operation is simple. An initial impulse in the plate circuit, however produced, induces a similar one in the grid circuit, which, if of proper polarity, will impress on the grid a sudden change in potential which may in its turn produce an impulse in the plate current in the opposite direction to the origi-

nal disturbance. This reaction then becomes self-sustaining, provided the resistance and hysteresis losses in the two circuits are not too great; and the amplitude of the oscillating current thus set up goes on increasing, taking energy supply from the B battery, until the losses in the circuits equal the increment of energy drawn from the battery. Whereafter an alternating current of perfectly constant amplitude and wave form is maintained. The frequency of this alternating current depends on the constants of the circuit, the inductance and capacity in the input or output circuits. But under certain conditions it depends to some extent also on the resistance in the grid leak, if this be used, and sometimes, but not usually, on the temperature of the filament and the B voltage.

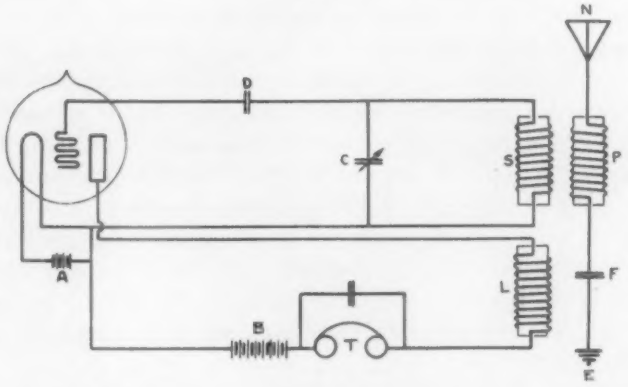
A few months after this type of circuit was first used for the production of alternating currents of audible frequency I first demonstrated the fact that weak *high-frequency* currents could equally well be generated, simply by substituting radio-frequency coils for the original iron-cored coils, and small variable air condensers for the large telephone condensers of the original experiment. And quite naturally, also, since I was at the time engaged chiefly in work on undamped wave radio transmission, this generation of radio frequency waves was first demonstrated in receiving heterodyne, or more exactly autodyne, signals. The circuit used at this early date, April, 1913, which was almost identical with that in Fig. 11—Fig. 12, shows the usual antenna receiving circuit, the usual secondary circuit connected across the grid and filament of the audion, but with another coil similar to the secondary in series with the telephone receiver, which in this case was abridged by a small condenser.

In the fall of that year my assistant, Mr. Longwood, and I discovered, largely by accident, that if the secondary receiving circuit be connected across the grid and plate, instead of as customary between the grid and filament of an audion, the circuit became a persistent oscillator, very simple and effective as a receiver of undamped wave signals. On account of the great sensitiveness of this combination the name "ultraudion" was applied to it. Countless modifications and adaptations of these two general types of oscillating audion circuits have been developed by radio men here and abroad. For their simplicity, the ease with which all the advantages of the beautiful heterodyne prin-

ciple of Prof. Fessenden and Vreeland can be realized, the clarity of note and range of pitch which the receiving operator can instantly command—coupled with a degree of sensitiveness of a different order from that of any other type of detector—these advantages very quickly relegated to the scrap-heap the ticker and tone-wheel; and at once placed the transmission by undamped waves upon an altogether different level from that of the older spark methods.

But the audion in an oscillating or an almost oscillating, or unstable, condition is also of great utility in detecting damped wave signals, or even radio telephone currents. If the two cir-

FIG. 12.



cuits, input and output, are so separated as to interact less energetically the oscillations become weaker and finally just cease to be generated. When in this condition a very feeble impulse, if properly attuned, can set the system into vibration. The resulting response develops an energy almost unrelated to the cause. Enormous magnifications are thus possible with a single audion, and spark signals have thus been received over the greatest span which it will ever be possible to reach on this earth—half way around the globe.

In receiving undamped wave signals, when the local oscillating receiver circuit is slightly out of tune with the incoming waves, the received currents on reaching the grid are amplified, first by the ordinary processes of the audion, and then combine with the local oscillations to produce "beat" notes, of audio-

frequency, which beat note currents are themselves amplified by the audion, before delivery to the telephone receiver. So sensitive is the pitch of this beat note to the slightest change of capacity or inductance in the circuit (when very high frequencies are employed) that in properly designed circuits a change of capacity of one-thousandth part of the electrostatic unit can be detected. A change of capacity which is caused by substituting coal gas for air in a condenser can thus be easily measured. Similarly can be demonstrated slight changes in resistance with temperature of conductors, the conductivity of flames, the permeability of liquids, etc. Very recently Prof. Blondel has utilized the audion in a balanced bridge method for measuring excessively slight differences in static potentials.

The uniform generation of electrical oscillations in a circuit by means of an audion is one of the most striking and fascinating of its applications. If these are of radio-frequency there is no sensible manifestation of their presence, but if of audio-frequency the telephone receiver or " loud speaker " reproducer may be made to give forth sounds from the highest pitch or volume to the softest and most soothing tones. Such wide range and variety of tone can be produced from suitably designed singing circuits that a few years ago I prophesied that at some future time a musical instrument, involving audions instead of strings or pipes, and batteries in place of air, would be created by the musicians' skill.

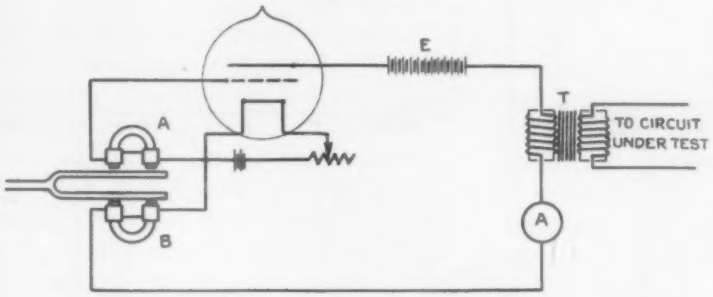
But lower frequencies, even to one oscillation per second, can be obtained from the audion. Pulsations suitable for submarine cable signalling, or for chronograph and time-pendulum work, can be had of remarkable constancy and reliability, free from all difficulties of speed regulation of motors, or of any moving parts. Or a combination of mechanical time-factors, and the electrical properties of the audion can be advantageously employed. For example, a tuning fork may be driven by electro-magnets, one connected in the grid circuit, the other in a plate circuit, as shown in Fig. 13.

The movement of the grid prong here induces an e. m. f. on the grid, which in turn controls the plate current through the other coil acting upon the other prong of the fork, thus sustaining its motion. If the two coils here shown are also closely coupled inductive reaction, or regeneration, is added to the mechanical.

and very powerful vibrations may be thus set up. Various modifications of this principle will suggest themselves to physicists, who desire sparkless generation of low frequencies of great constancy. Tuned relays, highly selective to definite frequencies, and where it is desirable to reduce the damping to zero or nearly zero, can thus be constructed. The above arrangement is due to Messrs. Eccles and Jordan.

A modification of this method of linking the audion with mechanical motion is the magnetic pendulum, actuated by the plate currents through electro-magnets and inducing in another coil properly tuned impulses which, if conveyed to the grid, control through almost senusoidal currents the successive pulls upon

FIG. 13.



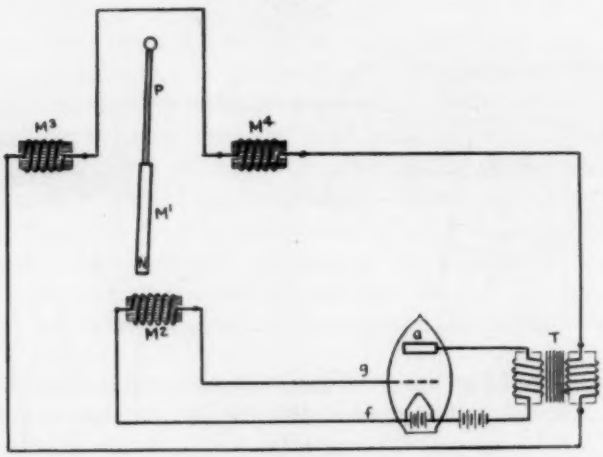
the pendulum (Fig. 14). When a second system identical with the first, but located at right angles thereto, is employed, the pendulum will be set into conical vibration, circular or elliptical as desired, and a revolving electric field will be produced, which can also be made to drive an armature or magnetized wheel at a certain definite speed.

There seems to be in fact no limit to the number of applications to which this three-electrode vacuum tube can be applied as a tool in the hands of the experimental physicist. Of especial value is the fact that it renders easily available devices having *negative electrical resistance*, as in the four-electrode device of Dr. Hull (styled the "dynatron")—or its equivalent in some mechanical form. For one fundamental property of the audion is that an electrical influence in one circuit may, through the grid, be made to produce effects in another circuit without appreciable reaction. For the energy absorbed by the control electrode may

be considered negligible—frequently less than that required in moving a galvanometer needle.

Then, and probably the most promising field of all, the arrangement of audions in cascade as amplifiers, of pulsating currents of any form or frequency—opens to the ear what the microscope has given to the eye—new regions of research in numerous and diversified fields, from physiology, for heart beats and breath sounds—to chemistry, where some even predict that we shall some day hear "the collision of individual atons with one another." During the war British army engineers used as many as nineteen audion bulbs in cascade circuit, amplifying preferably

FIG. 14.



the radio instead of the audion frequency currents. With such a series it is possible to detect with certainty alternating currents of one-ten-thousandth-millionth of a volt on the input grid—involving magnifications of the order of twenty thousand times. It is an everyday occurrence now to receive radio messages from Norway or Honolulu, on a closed-loop antenna one metre in diameter, using three or more audion amplifiers in cascade between this antenna and the detector, and sometimes a similar multi-stage amplifier for audio frequencies, between the detector and the telephone receiver.

Principles which though long understood were impossible of application to radio signalling have been made realizable by the

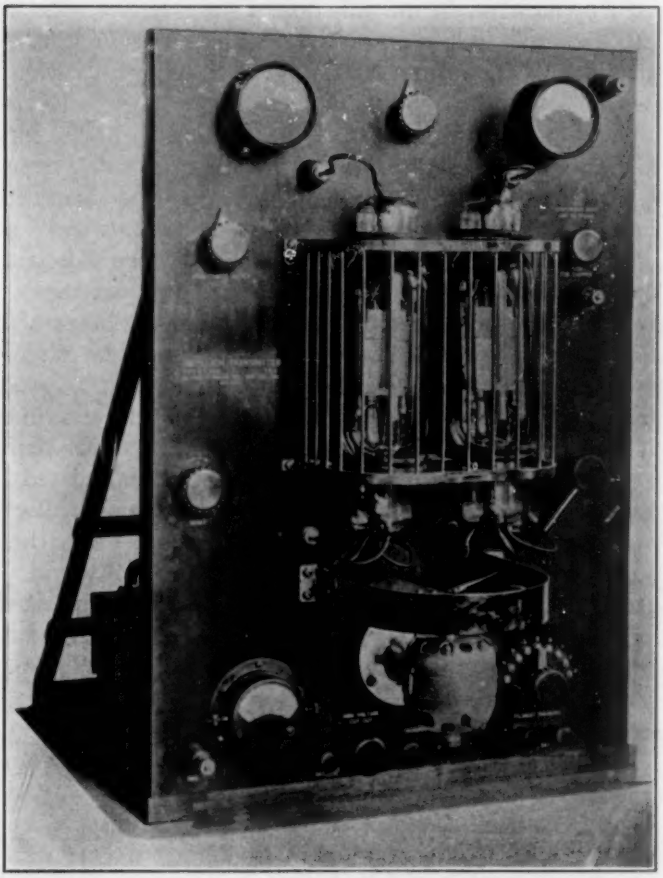
audion amplifier, and the scope and value of the new art immeasurably increased thereby. For example, the use of underground receiving antenna, the direction-finder, or radio-compass loop, the elimination of static interference by either of the above, or other methods—all such were compelled to await for their successful application the introduction of the grid electrode. Starting with the small bulb used in 1912–13 as a telephone amplifier and generator of minute electric oscillations for heterodyning purposes, I began the construction of larger sizes to be used in undamped wave transmission. At first spherical bulbs, three or four inches in diameter, and taking 50 watts of plate input energy, were considered large. Such rapid progress was made in improvement of design and construction of these so-called "power tubes," notably by the engineers of the Western Electric Co., that by autumn of 1915 a bank of several hundred tubes, their input and output electrodes connected in parallel, were installed at the Arlington wireless station. By a pyramidal circuit arrangement, whereby one oscillion tube controlled a group in parallel, these in turn controlling larger groups of oscillion tubes, some twelve kilowatts of undamped wave energy was delivered to the great antenna, all perfectly controlled or modulated by an ordinary telephone microphone. By this arrangement the voice was transmitted that year as far as Honolulu and Paris, thus fulfilling predictions made in 1909 to a very skeptical world.

In these Arlington tests the entire system was one of three-electrode tubes—for power generator, for current modulation thereof at the transmitter, and for detector and amplifier at the receiver. More recently Alexanderson, using his powerful high frequency alternator at New Brunswick, has controlled 80 kilowatts of antenna energy by means of his magnetic amplifier. This ingenious development of a Fessenden device was in turn controlled by a bank of large audion amplifier tubes, nicknamed "pliotrons," whereby the original microphone currents were sufficiently amplified to control the saturation currents necessary for the magnetic controlling device.

There are to-day grave differences of opinion among radio engineers as to what type of high-power radio transmitter will prove the key to the future—the high-frequency alternator, the Poulsen arc, or the oscillion. In my own opinion, the long-distance transmission art will shortly depart from true radiation

methods; and the a. c. generator, of comparatively *low* frequency, will be widely used for such subterranean, or submarine transmission, leaving for ship communication only the survival of

FIG. 15.

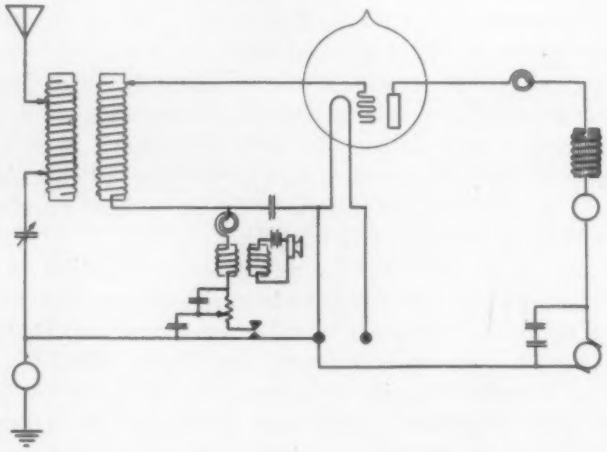


radio transmission, as it is known to-day. Such being the case, we will then have little use for *radio* transmitters of more than 20 to 50 kilowatts. For such transmitters I foresee the early use of a few large oscillion tubes, of say 5 kw. capacity each. Already we are making tubes capable of handling one and two kilowatts, using tungsten filaments and grids, and large anode

plates of tungsten or molybdenum. The efficiency with which several such tubes can operate in parallel, the ease with which an amplified voice current, acting upon their grids in parallel, can control their combined output make such a system almost ideal as a radio telephone transmitter. A typical oscillion transmitter utilizing two half-kilowatt tubes is illustrated in Fig. 15. The schematic circuit diagram for such a transmitter is shown in Fig. 16.

In the construction of these large tubes a thousand details must be scrupulously observed—in addition to the calculated physical

FIG. 16.



dimensions of the elements, the choice of materials, the method of seal, the preliminary treatment of the metals, their welding, the screening of the glass from bombardment, the various steps in the process of exhaustion—on careful observance of all these alone depends success in the manufacture of a high-power tube. A reasonably long life, of 500 to 1000 hours, is afforded by the tungsten filament, pure or alloyed with thorium; but this is by no means an ideal source of electrons. As such, tungsten, while preferable, is highly inefficient. By coating fine platinum ribbon with oxides of calicum, strontium, etc., or of the rare earths, similar to those in the Nernst glower, far higher emission efficiency is had, at lower temperatures, with resultant increase in life. But such oxide-coated filaments are fragile and very fre-

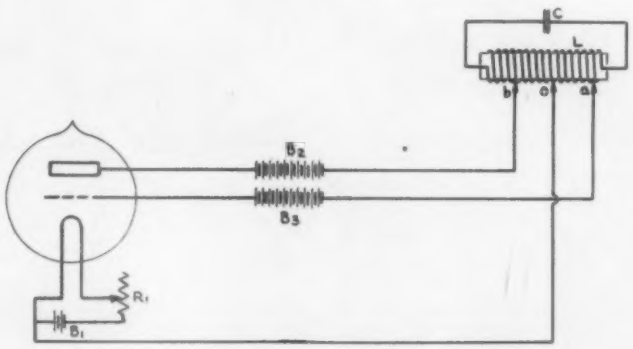
quently damaged during exhaust. Moreover, many types of coating lose their power of electron emission after a time. This method seems at best an imperfect makeshift. What the audion art awaits is a ribbon filament of some new, well-conducting alloy, wire drawn or rolled, of non-crystalline structure, emitting floods of electrons at a heat even lower than visibility. Reward awaits the metallurgist who first produces such a filament. For to-day the audion is being produced in quantities which in pre-war days would have been considered fantastic exaggeration. During the last months of the war the world production of such bulbs had attained the incredible rate of 1,000,000 per annum. And now the demand in America alone, chiefly from radio amateurs and experimenters, is at the rate of some 5000 per month, and constantly growing. And most of these latter are used singly or in two-step amplifier arrangements. During the war, however, thousands of amplifier and transmitter instruments, each requiring 3 to 9 bulbs, were in use—in earth telegraphy, in submarine listening, in telegraphy by ultra-violet or infra-red rays, in gun-spotting, airplane detection, etc., in addition to those required for ordinary radio telegraphy and telephony.

The necessary conditions for an audion to function as a generator of alternating currents have been the subject of exhaustive study by many investigators, notably by Hazeltine, Ballantine, and Mills in this country; Vallauri and Eccles abroad. There are to-day countless circuit arrangements whereby the audion may be caused to generate such currents; but in all of the practically useful ones, where considerable power is required, the inductive linking of the grid and plate circuits, analogous to that first used in 1912, is in one form or another employed. One of the simplest forms of such circuit is shown in Fig. 17. If there is no time lag in the electronic stream behind the pulsations of grid voltage, as is the case in a highly exhausted tube (up to frequencies of ten million per second), then the above arrangement becomes an alternating current source whose frequency depends upon the natural frequency in the LC circuit. The period of this oscillation is very nearly $2\pi\sqrt{LC}$ if the resistance, r, of the external plate circuit is small, the resistance, or reactance, p, of the plate-filament gap is great, and provided the mutual induction, m, between the inductances in the grid-filament and plate-filament circuits is just sufficient to maintain the oscillations.

If, then, $m \geqq \frac{1}{k}\left(\frac{L}{p} + r.C\right)$ this oscillating condition is realized; and K in this formula can be defined as the "amplification factor."

One of the latest developments in the oscillion transmitter is the application of alternating current for the plate voltage supply. Sixty cycle current is taken from a lamp socket, stepped up to 500 or 10,000 volts (according to the size of the transmitter)—the two halves of the cycle rectified through two-electrode vacuum valves, this rectified current stored in a suitable condenser, smoothed out by an appropriate "filter" circuit, and finally delivered as high-voltage direct current to the plate-filament circuit of three-electrode oscillator tubes. The filaments of both recti-

FIG. 17.



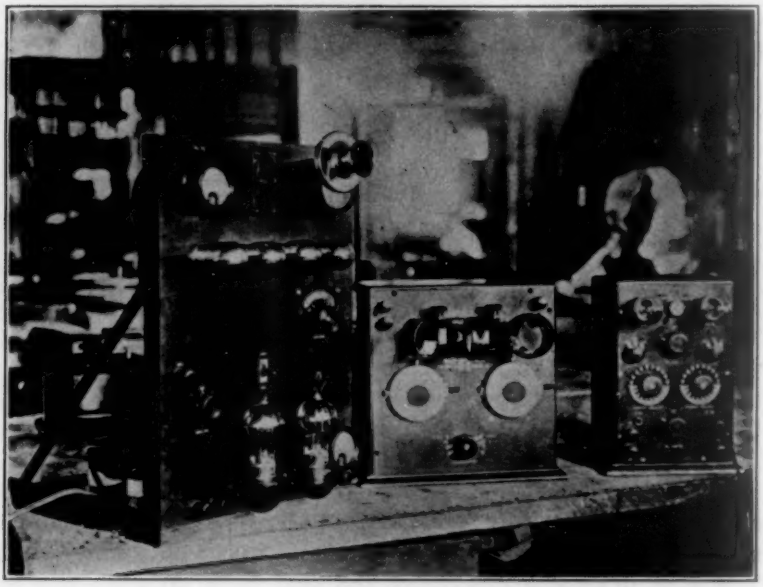
fiers and oscillators are lighted from the low-voltage windings on the one transformer. Such an arrangement does away with the motor generator converter, and even with 60 cycle supply gives surprisingly clear voice transmission. A small set of this type employing two rectifier and four small oscillating audions in multiple is shown in Fig. 18. With this small unit, consuming 50 watts and putting three-quarters of an ampere in an average antenna, one has recently telephoned fifty miles.

The developments by the engineering staff of the Western Electric Company of the audion amplifier as a telephone repeater, since my first demonstration to them of its possibilities in that field, are beyond all praise. The zeal and rare understanding of the elements of the problem with which this staff of trained men developed the amplifier and applied it to the long-sought trans-

continental telephone line stand unique in the annals of brilliant achievement in electrical engineering.

The time was ripe. Had the audion amplifier been presented at a much earlier date it is unlikely it would have then met the warm welcome which twenty years of futile search for the telephone repeater had earned for it. It was the irony of inventive fate that this revolutionary telephone device was to come, not

FIG. 18.



from those whose efforts had for years spun in the old rut of the receiver-microphone "siameesed" together, but from an art younger than telephony, from a device conceived for a quite different application—a wireless telegraph detector.

"From small beginnings the transcontinental line has been evolved. One element after another came. First the telephone receiver of Bell; then the Berliner—Edison microphone; then adequate line construction; the Pupin coil to prevent voice distortion—and finally the one missing link, the Audion Amplifier. Try to imagine one of the electronic carriers of the voice currents in this amplifier, and contrast it with a carbon granule of

a microphone transmitter of the early telephone relays. Compare a soap bubble with a load of coal, and you will have some relative idea of the distinction between the delicacy and elegance of the audion and that of the old microphonic relay." A more revolutionary step was never taken in the history of electrical engineering.

A repeater suitable for our present wire telephone system should supply energy amplification sufficient to restore the attenuation produced by twenty miles of standard cable. This actually means that the repeater must be capable of delivering 256 times as much energy as it receives; that is, possess a telephone efficiency of some 26,000 per cent., and this without appreciable distortion of the most intricate of voice current waves, involving all frequencies from 100 to 3000 per second. Any repeater or amplifier which produces distortion of the speech currents is to that extent unfitted for use in tandem operation, because the distortion is cumulative in the successive repeaters; and mechanical amplifiers generally, and even the best of that type, produce distortion.

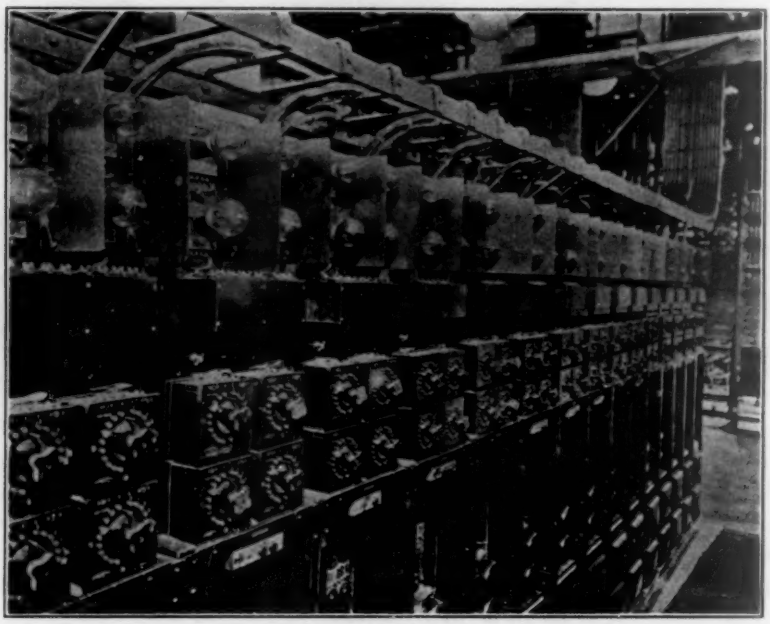
A large amount of unnecessary secretiveness or mystery was for some time thrown around the type of telephone repeater which made possible transcontinental telephony.

A well-known telephone engineer has recently stated that the audion amplifiers used by the American Telephone and Telegraph Company are practically distortionless, and are commercially used in tandem operation in regular installations, and were so used in the first transcontinental line, which would have been impossible without the use of the tandem arrangement. By actual trial over cable circuits approximately one thousand miles in length it has been found that as many as thirty of these audion amplifiers can be connected in tandem and produce excellent speech at the receiving end of the line. This engineer is authority for the statement that computation shows the attentuation of a cable circuit of this length to be so enormous that if all the power received on the earth from the sun could be applied in the form of telephone waves to one end of the line, without destruction of the apparatus, the energy received at the other end would be insufficient to produce audible speech without the use of amplifiers; whereas with 30 amplifiers used in tandem the relatively minute energy of ordinary telephone speech currents at the transmitting

end produced speech in the receiver at the opposite end which was both loud and clear, the amplification due to such a tandem arrangement of tubes being of the order of 10^{50}.

The audion which has been evolved to meet these requirements, most rigorous of all its numerous applications, differs in many details from the detector or the oscillating audion. The presence here of gas ionization sufficient to cause appreciable dis-

FIG. 19.

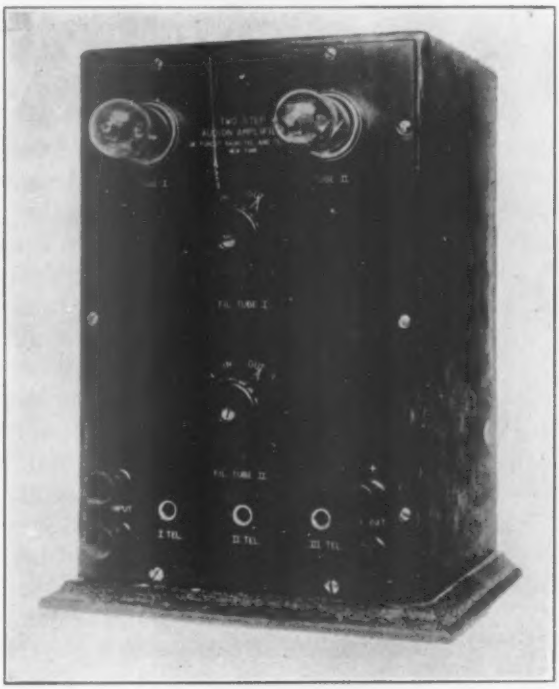


tortion cannot be tolerated, neither must the grid be permitted to be positive at any phase of the cycle of impressed voltage. A hundred other minor requirements, small yet difficult of realization, have been patiently achieved by our telephone engineers, who now state that "the amount by which it (the audion amplifier) fails to meet all the requirements for a perfect repeater is so small as to be negligible except under the most rigorous conditions."

The illustration (Fig. 19) conveys a more vivid idea than any description of the thorough completeness with which the

American Telegraph and Telephone engineers have applied the audion repeater to the commercial long-distance telephone service. It illustrates a typical group of repeater racks, each rack carrying two complete repeaters. This view was taken at one of the main repeater stations on the Boston-Washington underground cable line, located at Princeton, N. J.

FIG. 20.

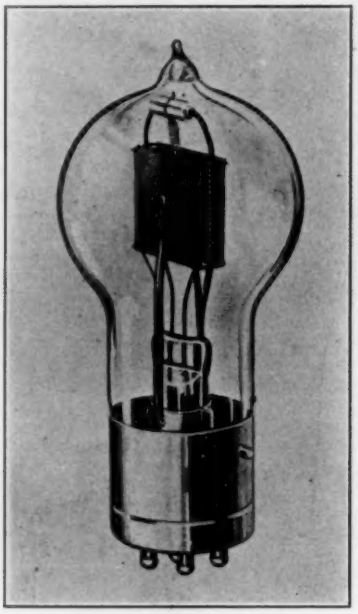


Two-stage audion amplifier.

Popular attention has been attracted to the success of the recently announced application to line wires of wireless methods of transmission, reception and tuning, whereby multiplex telegraphy and telephony have been made possible over wires already loaded down with their ordinary communication. The original ideas of such multiplex telephony date back to the early nineties, when John Stone Stone, Hutin and Leblanc disclosed methods all involving the same principle, that several alternating currents of

superaudio-frequency, each from a separate source, could be directed over the same wire or pair of wires, each be modulated or controlled by its own microphone, or Morse key, and at the receiving station each frequency taken off by its own properly tuned circuit, and there retransformed into its own original telephone or telegraph current. But none of these early investigators utilized at that time the all-necessary integrating detector which

FIG. 21.



50-Watt amplifier.

was alone capable of retransforming the modulated high-frequency wave-trains back into their original audio-frequency currents. Here again the wire telephone requirements had to await the advent of a radio-detector.

General (then Captain) George O. Squier in 1910 carried out certain experiments which are destined to become classic as the new art of wired-wireless attains the important commercial proportions to which it is unquestionably destined. He, for the first time, used a constant, reliable source of undamped electric

currents of high frequency for the transmitter, and an audion detector between each tuned receiving circuit and its telephone receiver. By this combination multiplex telephony became at once a realized fact.

But so long as a high-frequency alternator was required at each transmitter station the wired-wireless idea could not become commercialized. Its first cost, the size and weight of it with its motor, its delicacy of speed regulation, its limitation to relatively low frequencies, all made this impossible. So again an important development was compelled to await the advent of the oscillating audion.

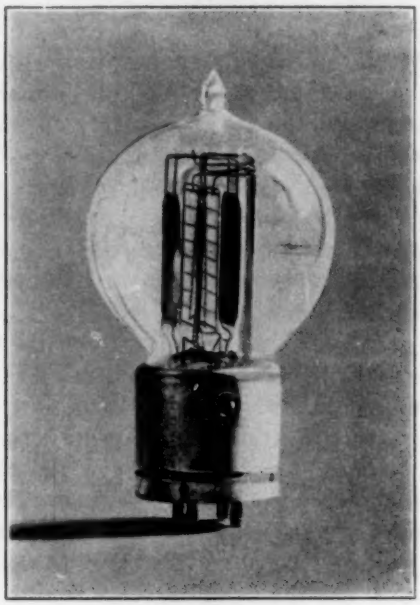
Supplied from a common filament-lighting battery, a common "B" battery, or d. c. generator, any desired number of tiny alternating current generators, each driving its own easily tuned circuit, can now be assembled in a small central station. The grid of each oscillator is voice-controlled from its local telephone circuit, and as many high-frequency "carrier" wave-trains superimposed upon a single trunk line pair, as it may be feasible to use without interferences between the modulated frequencies of the several conversations.

At present carrier frequencies ranging from 5000 to 25,000 have been used commercially over a single pair of telephone wires, between Baltimore and Pittsburgh. A zone of frequencies of 2500 is allotted to each conversation, which permits of eight simultaneous telephone conversations over the line, in addition to the usual "physical circuit" conversations. The constant frequency generated by each individual oscillion lies in the middle of each allotted zone of wave-frequencies, but the modulation of this "carrier wave" by the voice currents results in a wide band of frequencies (analogous to a spectrum band) on each side of the particular carrier-wave frequency. This means that at the receiving station it is preferable to employ, instead of a circuit attuned to the single frequency of the carrier-wave, a "band-filter," or combination of several tuning elements (inductance and capacity). This band-filter, then, is equally receptive to any wave-frequency lying within the prescribed limits, say 1,250 cycles on each side of the carrier-frequency, but offers very high impedence to all frequencies above or below the limits of the band-frequencies. By eight such band-filter receiving circuits the eight conversations are segregated, each delivered to its own

proper audion detector and sent out on its own local telephone line.

But it is by no means necessary to limit wired-wireless to the use of such low frequencies as we have been considering. Certain tests were recently carried out in Canada which proved conclusively that frequencies as high as 500,000 per second can be used over telephone lines, including several miles of cable, without harmful attenuation. This demonstration widens very

FIG. 22.



Western electric audion amplifier.

greatly the range of frequencies available for wired-wireless, with hope for a corresponding increase in the number of conversations, or telegraph communications, which can be placed upon a single pair of wires, or group of pairs. Moreover, with such high frequencies (say from 100,000 to 300,000 per second) the necessity for complicated band-filter receiving circuits vanishes, with obvious attendant advantages.

Wired-wireless is the youngest of the large family of methods for electrical communication of intelligence. He is indeed a

bold prophet who will to-day attempt to foretell the limits of its application. That the great saving in line costs, the vast multiplication of available channels of long distance communication which it makes possible will work profound changes in our present methods of business, cannot be questioned. Thus again it seems evident that the audion is destined to play a leading rôle in the work of knitting more closely the people of this land, and of all lands.

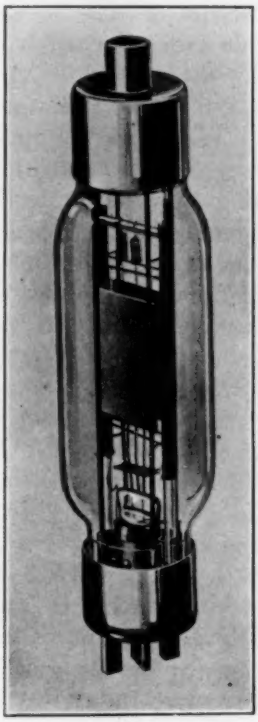
We have briefly recounted some of the main achievements which the three-electrode audion, or triode, has to its credit. Let us now consider some of the possibilities of its future. From its invention until 1912 it attracted an almost negligible interest in the scientific world. A year after the audion was first brought to the attention of the engineers of the American Telegraph and Telephone Company that corporation acquired exclusive license under all the audion patents for wire telephone purposes. Thereupon the research men of that organization initiated an elaborate line of investigation of the device, which about that time began to interest other scientists in America and abroad. Prior to 1914 not a dozen articles on the audion had appeared in scientific publications. To-day it is impossible to pick up a magazine directed to physics or electric communication without finding one or several papers dealing with some of what Dr. Eccles styes "the protean properties of the ubiquitous three-electrode tube."

Writing in the *Radio Review*, Dr. Eccles (who is affiliated with the British Marconi Co.) says: "The most important single instrument in modern wireless practice is the three-electrode thermionic vacuum valve, for it enters into every main division of the subject—it plays a dominant part in the generation of oscillations, the detections of signals, and in the amplification of feeble voltages and currents. Its arrival and devolpment have, besides, helped greatly towards the success of apparatus and methods that might otherwise have remained almost failures."

Dr. Eccles has outlined the present status and forecast of the future of the audion so clearly that I am constrained to quote further his words, as those of an unbiased observer: "During the war, hints reached the civilian that a revolution was taking place in wireless telegraphy, the principal agent in which was reported to be an instrument called a 'valve,' a 'lamp,' or a 'tube.' This instrument seemed to have arisen suddenly into a predomi-

nant position among all the apparatus of the wireless experimenter and operator, and appeared to be of use in every corner of his outfit. The complete name of the instrument is the three-electrode thermionic vacuum tube. It must be emphasized that it is the three-electrode valve, and not the valve with two electrodes, that has been responsible for the overthrowing of the old

FIG. 23.



1 Kw oscillion.

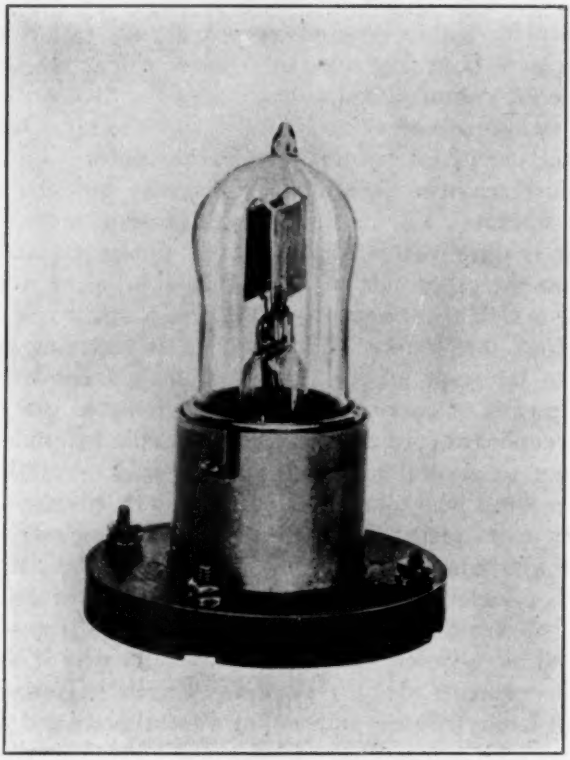
methods and apparatus. That it has been a veritable revolution can be seen by comparing the common practice in wireless telegraphy of 1914 with that of 1919. In 1914 practically all the most powerful transmitting stations in the world generated waves by sparks and signals were receivel at nearly all stations by means of crystal or magnetic detectors. The spark method of generating waves involved the use of very large an-

tennæ for spanning great distances; and at the receiving stations which wished to listen to stations more than even 100 miles away very large aerial structures were customary. But if we look at the state of affairs to-day we find most of the high-power stations for long-distance transmission are 'continuous wave' stations; that is, they produce uniform uninterrupted waves instead of a series of short gushes made by sparks; while at the receiving end new modes of detecting these continuous waves appropriate to, and taking advantage of, their uniformity in character have been introduced. This is where the three-electrode tube, in various adaptations, enters the arena. Taken together, the improvements at both ends of the span have made possible the use of smaller antennæ at transmitting stations, and have almost removed the necessity for any antenna at all at receiving stations. For example, under reasonable weather conditions, it is quite easy to listen to the messages coming from stations on the other side of the Atlantic by using a receiving circuit of which the receptive element is a small coil of wire, three to four feet square. Thus, so far as receiving goes, it is possible to intercept all the great stations on one-half of the globe by means of apparatus contained wholly in one room, or even in a cupboard. In accomplishing this the magnifications in use amount to several hundred-thousand-fold. All this is the work of a thing which looks like an ordinary electric-light bulb with a few extra pieces of metal in it—the three-electrode tube."

Years ago what physicist did not look at the simple, self-contained, noiseless incandescent lamp, consider it as an ideal source of electro-magnetic waves of a wide spectrum—of heat, visible, and ultra-violet radiation, and wonder why it should not be made to generate also waves of any length? To-day that incandescent lamp, with the addition of a metal plate and wire grid, has become such a generator. Undamped Hertzien radiations of a few centimetres' wave-length can be generated by audions specially designed to give minimum capacity between the three-electrodes and their lead-in wires. From these short waves, representing alternating current frequencies of some hundreds of millions, down to those of one or two per second, the electric-wave spectrum afforded by the oscillating audion is continuous. Consider this fact in connection with the almost infinite sensitivity of the device as a detector, and its unlimited power as a magnifier,

or amplifier, and one realizes something of the value of the three-electrode vacuum tube to the physicist and the inventor. To the former, however, the keenest interest lies perhaps in the audion itself, because there is no known piece of electrical apparatus linked so directly with the most recent work on the structure

FIG. 24.



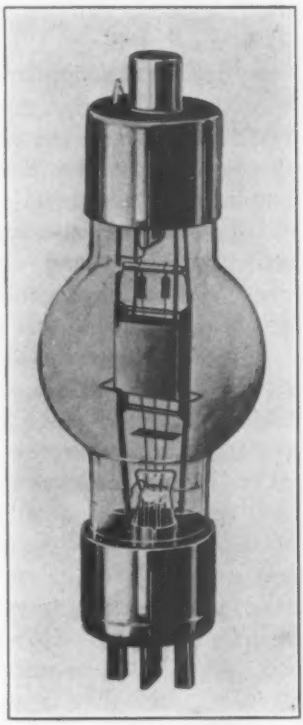
"VT-21" signal corps audion.

of matter. A prominent British physicist has recently remarked: "It is probable that there is no other sphere where research work has had such a combination of immediate practical value and intense theoretical interest."

Many an early experiment in telegraph transmission or reception by wire or wireless, long since abandoned as too limited in

range, can to-day be revived to the great benefit of man. Calculations have shown that with a littoral cable stretched for 50 miles on each side of the Atlantic, and carrying some forty amperes of 20-cycle alternating current, telegraphic communication by conduction or leakage currents should be possible, using the audion

FIG. 25.



¼-Kw oscillion tube.

as detector and amplifier. I venture to prophesy that within a few years the tall towers and the atmospheric disturbances, which have for two decades been esteemed necessary evils in trans-oceanic wireless signalling, will be regarded with those sentiments which we now bestow upon the coherer and the spark.

But more than this. Signalling by conduction currents of relatively low frequency will soon be practiced through the earth as well as water; and we will find the antennæ of the future thrust

upside down, as into abandoned oil-well borings, and making contact with deep semi-conducting strata, at points separated by a few miles; the two inverted antennæ of such a transmitter connected by an overhead power transmission line containing the alternating current generator and signalling device; and a similar arrangement for receiving. Then our wireless messages will go through the earth's crust, or possibly by a more direct path, and not around the earth's surface, to be tangled up as at present with a bewildering snarl of static ravellings. The audion amplifier stands ready to lead us back to the simpler methods of Morse and Lindsay, meritorious methods long ago abandoned because of the lack of an electric ear of indefinitely great sensitiveness.

The future of radio signalling at sea lies with the telephone rather than the telegraph. The simplicity, the reliability with which the medium of an undamped wave-carrier, ideally suited for voice transmission, can now be had will rapidly limit the crudity and laboriousness of the Morse code signalling between ships. Yet to-day scarcely the dawn of this new epoch has been seen. Vessel owners are to-day almost as skeptical regarding the practicability and utility of the radiophone as we pioneers found them towards the wireless telegraph sixteen years ago!

In the future during fogs at sea a short-wave radio telephone will be used to prevent collisions, distances being determined (as wall as direction) by conversation, whistled signal or bell, and a calibrated stop-watch. This service will be quite independent of the long-range wireless signalling. The new radio has also a wide field of usefulness in telephoning between islands, thousands of which will never be linked by cable. Other useful fields await in sparsely peopled countries, between mines, oil wells, forest patrols, from express trains, etc. The future of aviation will be found linked with radio telephone, for a score of different purposes. Telephony by audion transmitter, receiver, and amplifier not only carries the complexes of human speech without distortion, but delivers them where human speech itself is impossible otherwise—amid the deafening motor and propellor noises of the airplane, from one to five miles above the earth.

Little imagination is required to depict new developments in radio telephone communication, all of which have lain fallow heretofore awaiting a simple lamp by which one can speak instead of read.

ON THE THEORY OF TONE REPRODUCTION, WITH A GRAPHIC METHOD FOR THE SOLUTION OF PROBLEMS.*

BY

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THE problem of ascertaining the exact extent to which it is possible by the photographic process to produce a pictorial representation of an object which will, when viewed, excite in the mind of the observer the same subjective impression as that produced by the image formed on the retina when the object itself is observed has engaged the attention of workers in the field of photography for many years. There are many phases of the subject to be considered, and a complete treatment requires a careful analysis of the various factors upon which depend the operation of our visual perception of space and spatial relations. A complete analysis, therefore, leads not only into the realm of physical science, but also into those of psychology and philosophy. It is not the purpose of this paper to present such a complete treatment, but to deal with a single phase of the subject. A careful consideration of the various factors upon which depends our visual perception of space leads to the conclusion that brightness and brightness differences (*i.e.* contrast) are by far the most important factors which are reproducible by the photographic process. The form factor (including size, shape, position, definition, etc.) to which so much importance is usually attached and which is conditioned by the performance of the image forming system, depends for its effectiveness upon the proper rendition of brightness differences. The proper reproduction of brightness and brightness differences, therefore, is of preëminent importance, and it is with this brightness factor and the possibility of its correct reproduction by the photographic process that this paper will deal.

This problem of tone reproduction, as it is commonly called,

* Communicated by Dr. C. E. K. Mees. Communication No. 88 from the Research Laboratory of the Eastman Kodak Company.

has frequently been regarded as requiring only the correct reproduction in the picture of the actual physical brightness of the original, and of the actual contrast relations existing between various areas of the object. When we consider, however, that a given brightness or contrast may produce an entirely different subjective impression, depending upon the state of adaptation of the observer's eye, it is obvious that such a treatment of the subject cannot afford a complete solution of the problem. The problem may, in fact, be divided into two general parts, the one, which we may term the objective phase, dealing with the reproduction of the actual physical brightnesses and capable of being completely solved by purely physical methods; the other, the subjective phase, including a consideration of those factors which determine the nature of the subjective impressions produced by the action of given physical stimuli under various conditions, and requiring the use of psycho-physical methods and data for its adequate treatment.

Hurter and Driffield,[1] who may be considered as the founders of the science of photographic sensitometry, treated this subject to some extent, but confined themselves to a consideration of the objective phase. Lord Rayleigh[2] also has treated, although rather briefly, the objective phase of the subject. F. F. Renwick has made valuable contributions to the solution of this problem at various times, dealing in particular with the brightness reproduction possible when using the region of underexposure,[3] and later presenting a more complete treatment of the entire subject both from the objective and subjective viewpoints.[4]

Recently A. W. Porter and R. E. Slade[5] have published a paper on the subject in which they take exception to some of the conclusions reached by Hurter and Driffield, and outline the relations which they consider essential for the solution of the problem. They also deal only with the objective phase, the reproduction of the actual physical factors. Following this, two short papers of a somewhat controversial nature dealing with special cases of the tone reproduction problems have appeared, one by

[1] *Jour. Soc. Chem. Ind.*, May, 1890, and February, 1891.
[2] *Phil. Mag.*, vol. xxii, 1911, p. 734.
[3] *Phot. Jour.*, vol. xxxvi, 1913, p. 127.
[4] *Phot. Jour.*, vol. xl, 1916, p. 222.
[5] *Phil. Mag.*, vol. xxxviii, 1919, p. 187.

Mr. F. F. Renwick [6] and the other by Messrs. Porter and Slade.[7] Finally Mr. Renwick [8] has published a paper in which he gives in detail the method by which he obtained the results previously published (*loc. cit.*) relative to the objective phase of the subject. His conclusions are in substantial agreement with those arrived at in the following treatment of the subject although a quite different graphic construction was used.

During the past five years a large amount of work has been done in this laboratory on the theory of tone reproduction, and a satisfactory solution for the objective phase was obtained some two or three years ago. Application of this method was made to a special problem, the determination of the color coefficients of various selective photographic images, the results being published by the author in collaboration with R. B. Wilsey in the JOURNAL of THE FRANKLIN INSTITUTE, Vol. 185 (1918), p. 231. While the precise method of procedure in the paper cited (see page 253) applies only to the special problem considered, which was not fundamentally tone reproduction, use was made of the basic principle which constitutes the method for the solution of the tone reproduction problem to be presented in this paper. The publication referred to is mentioned merely as an instance of a special problem in photographic research to which the more general method may advantageously be applied. Simultaneously with the work of tone reproduction, research in the field of visual sensitometry has been in progress, which has resulted in data applicable to the solution of the subjective phase of the more general reproduction problem. The results of this work have been published as communications from this laboratory by P. G. Nutting,[9] Julian Blanchard,[10] and Prentice Reeves.[11]

While some particular details of the subjective data are still lacking, it is felt that sufficient information is now available to establish the general nature of the function necessary for the con-

[6] *Phil. Mag.*, vol. xxxviii, 1919, p. 637.

[7] *Phil. Mag.*, vol. xxxviii, 1919, p. 637.

[8] *Phil. Mag.*, vol. xxxix, 1920, p. 151.

[9] JOURNAL OF THE FRANKLIN INSTITUTE, vol. clxxxiii, 1917, p. 287; *Trans. Ill. Eng. Soc.*, vol. xi, 1916, p. 939.

[10] *Phys. Rev.*, vol. xi, 1918, p. 81.

[11] *Jour. Opt. Soc. Amer.*, i, 1917, p. 148; *Astro. Phys. Jour.*, xlvii, 1918, p. 141; *Psychol. Rev.*, vol. xxv, 1918, p. 330.

version of objective reproduction into its subjective equivalent. In the meantime further work is being carried out in order to make possible a more precise quantitative evaluation of this function.

SIMPLIFYING ASSUMPTIONS.

In order to simplify the subject and bring it within the limits of a single paper, it will be necessary to make certain simplifying assumptions. Since the sensitivity of the photographic plate to radiation of different wave-lengths is in general radically different from that of the eye, objects in which color is present have not in general the same brightness when considered from the visual standpoint as when the evaluation is in terms of the photographic plate.

Let us, therefore, assume that all areas of the object considered are both visually and photographically non-selective (*i.e.*, colorless), and further that the optical system forming the image of the object on the negative material is likewise non-selective. Under such conditions values of visual brightness are directly proportional to photographic brightness. Thus this treatment will deal with brightness relations uncomplicated by any consideration of selectivity. Let us further assume that all photographic deposits considered are also non-selective in order that visual and photographic density values may also be considered as identical.

TERMINOLOGY AND SYMBOLS.

The problem to be treated involves so many operations, materials and inter-relations that it is of considerable importance at the outset to adopt a logical system of terminology and symbols. In order to obtain a satisfactory foundation, let us consider briefly the various steps in the complete cycle involved in obtaining a reproduction by the photographic process. An image of the object (O) must be formed on the negative material (X) by a suitable optical system. Under our first assumption it will be unnecessary to distinguish between the photographic and visual characteristics of the object. The characteristic of the object of interest is its brightness, while that of the image formed on the negative material is the illumination. The image illumination is transformed into an exposure by the action of the time factor. The exposed sensitive material is now developed, thus being transformed into a negative, N. The essential characteristic of the

negative is transmission or density. The negative is now used to form an image, either by contact or projection, on the positive material *Y*. The most useful specifications of this image is its illumination, for the determination of which it is necessary to know the illumination incident on the negative. The illumination of the image is transformed into an exposure by the factor of time. The exposed positive material is now transformed by development into a positive, *P*, of which it is necessary to know the density values. The positive becomes an objective reproduction, which in order to avoid confusion in the system of terminology we will refer to as the "material" reproduction, when it is illuminated, and is characterized by its brightness values. The character of the subjective reproduction resulting when this objective reproduction is viewed by an observer is dependent upon its brightness values and the retinal adaptation of the observer. Finally the evaluation of the subjective reproduction relative to the subjective impression due to the object, which we shall for sake of brevity call the "subjective object," involves a consideration of the brightness values of the object and the retinal adaptation existing when viewing that object.

The "things" involved therefore are:

	Symbol
1. Object	*O*
2. Negative sensitive material	*X*
3. Negative	*N*
4. Positive sensitive material	*Y*
5. Positive	*P*
6. Material Reproduction	*MR*
7. Subjective Reproduction	*SR*
8. Subjective Object	*SO*

The first six of these are objective or physical in nature, while the last two are subjective or perceptual. An evaluation of *O* in terms of *MR* gives a function which defines the extent to which actual objective reproduction of brightness is obtained under the limiting conditions assumed while an evaluation of *SO* in terms of *SR* gives the function required to determine the reproduction of the subjective impression.

The symbols as indicated for these "things" will be used as subscript letters attached to the symbol for the various physical factors applying to them.

The physical factors are:

	Symbol
Radiant Flux	F
Illumination	I
Brightness	B
Reflection Coefficient	R
Transmission Coefficient	T
Exposure	E
Time	t
Density	D

Some of the fundamental relations existing between these factors are:

$$E = I \cdot t.$$
$$D = \log \frac{1}{T}$$
$$B = I \cdot R \text{ or } I \cdot T.$$

If, for a given absorbing layer,

F = Incident Flux, and
F' = Transmitted Flux (or Reflected Flux),

$$T = \frac{F'}{F}$$
$$R = \frac{F'}{F}$$

As an example of the use of subscript letters according to this system:

E_x = Exposures given to negative material.
E_y = Exposure given to positive material.
D_n = Density of negative.
T_n = Transmission coefficient of negative.
B_o = Brightness of object.
I_n = Illumination incident on the negative (during printing).

Other particular values of the physical factors are indicated in a similar manner.

In Table I is given a schematic outline showing the various steps in the computation of the final result of a given tone reproduction problem. It will be noted that the process is divided into ten distinct steps represented by the Roman numerals I to X. The necessary factors required at each step are designated by the corresponding Arabic numerals. In the parenthesis designated by the letters A, B, C, etc., are statements either verbal or sym-

bolic of the transformation factors which convert the factor of one step into that of the next succeeding step. As the starting point, I, it will be noted that the "subjective object" is taken, by which is meant the subjective impression of brightness and brightness contrast excited in the mind of the observer. This impression, it is obvious, is the thing which it is desirable to reproduce rather than the actual physical brightness values which are measured by the usual physical methods. In practice, however, it is more convenient to take as the actual starting point of the operation the measured brightness values, B_o, of the object and to evaluate the subjective relation between B_o (II) and B_{so} (I) relative to that between B_{mr} (IX) and B_{sr} (X) after having obtained the necessary values of B_{mr}.

TABLE I.

I. The Subjective Object (SO).
  1. Subjective brightness of object (B_{so}).
    A. (Adaptation level of observer when viewing object, A_o $B_{so} = f(A_o)$.)
II. Object (O).
  2. Brightness (B_o).
    B. (The constant of the image forming system, K_x.)
III. Image on the X (negative) material.
  3. Illumination $(I_x) = B_o \cdot K_x$.
    C. (Exposure time, t_x.)
IV. Exposure on the X (negative) material.
  4. Exposure $E_x = (I_x \cdot t_x)$.
    D. (Development, fixing, washing, drying, intensification, reduction, etc. Specified by $D_n = f(E_x)$.)
V. Negative (N).
  5. Density, D_n, or Transmission, T_n.
    E. (Illumination, I_n.)
VI. Image on the Y (positive) material.
  6. Illumination, $I_y = (T_n \cdot I_n)$.
    F. (Exposure (printing) time, t_y).
VII. Exposure on the Y (positive) material.
  7. Exposure $E_y = (I_y \cdot t_y)$.
    G. (Development, washing, fixing, toning, etc. Specified by $D_p = f(E_y)$.)
VIII. Positive (P).
  8. Reflecting Power, R_p.
    H. (Incident Illumination, I_p.)
IX. The Material Reproduction (MR).
  9. Brightness $(B_{mr}) = (R_p \cdot I_p)$.
    I. (Adaptation level of observer, A_{mr}. $B_{sr} = f(A_r)$.)

X. The Subjective Reproduction (SR).
10. Subjective Brightness (B_{sr}).
J. (The relation between B_{sr} and B_{so} determines the extent to which the desired subjective impression of tone is accomplished. $B_{so}=f(B_{so})$.)
I. The Subjective Object (SO).
1. Subjective Brightness of Object (B_{so}).

THE NECESSARY DATA.

Before considering the method of obtaining the tone reproduction solution, it will be well to consider briefly the individual groups of data which must be utilized. These may be summarized as follows:

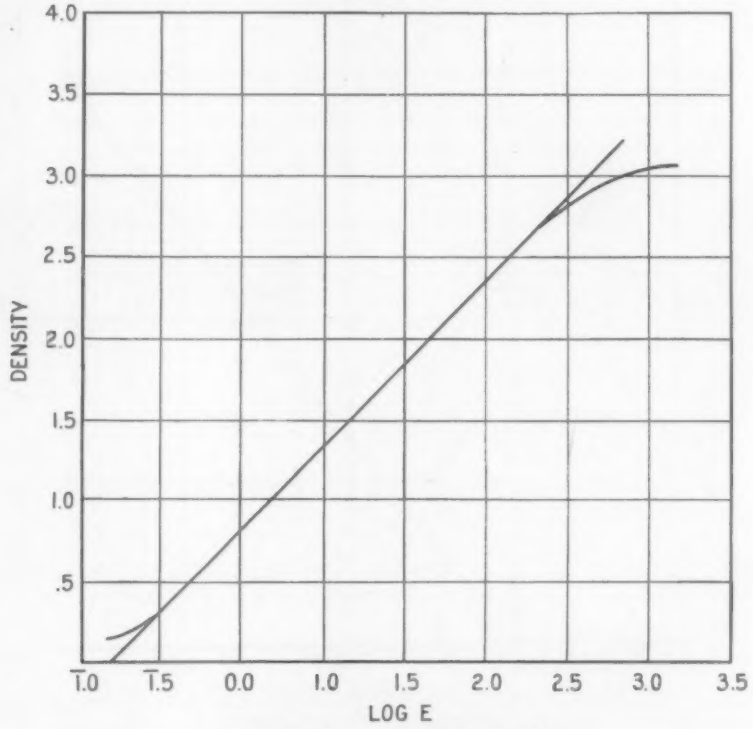
1. Relative to the Observer:
   A_o Adaptation level of eye when observing the object.
2. Relative to the Object:
   B_o Brightness values for various areas of the object.
3. Relative to Image Forming System:
   K_g Factor converting B_o to I_g.
4. Relative to Negative Material:
   $D=f(E)$ The H and D curve of the material.
5. Relative to Printing System:
   I_n Illumination incident on negative during printing.
6. Relative to Positive Material:
   $D=f(E)$ The H and D curve of the material.
7. Relative to Material (Objective) Reproduction:
   I_{mr} Illumination on the print during observation.
8. Relative to the Observer:
   A_{mr} Adaptation level of the eye while observing the reproduction.

As a typical example of the data mentioned under No. 4, the curve in Fig. 1 is given. This is for a typical negative material of good quality, the ordinates being values of density (D) and the abscissæ the corresponding exposure plotted on a suitable logarithmic scale. In Fig. 2 is given a typical example of the same function ($D=f(E)$) for a positive material, in this case a photographic developing out paper. In case the positive is made on a transparent base, the curve will be of the same general type, but resembling more closely with respect to absolute values the curve shown in Fig. 1. In order to determine the relation between the objective and subjective reproduction, it is necessary in addition to the factors mentioned previously to use the sensibility function of the eye. In Fig. 3 are plotted the curves showing the retinal sensibility to brightness and brightness differences as a function of adaptation level. These curves are obtained from

data by Nutting and Blanchard, and constitute the most reliable information available relative to the subject.

Curve A is plotted with values of sensation (S) as ordinates against the logarithm of the field brightness (B). Curve B is the first derivative of A, and is plotted with values of $\frac{B}{\triangle B}$ as ordinates. This curve gives the contrast sensibility of the eye for the

FIG. 1.



Characteristic curve of negative material.

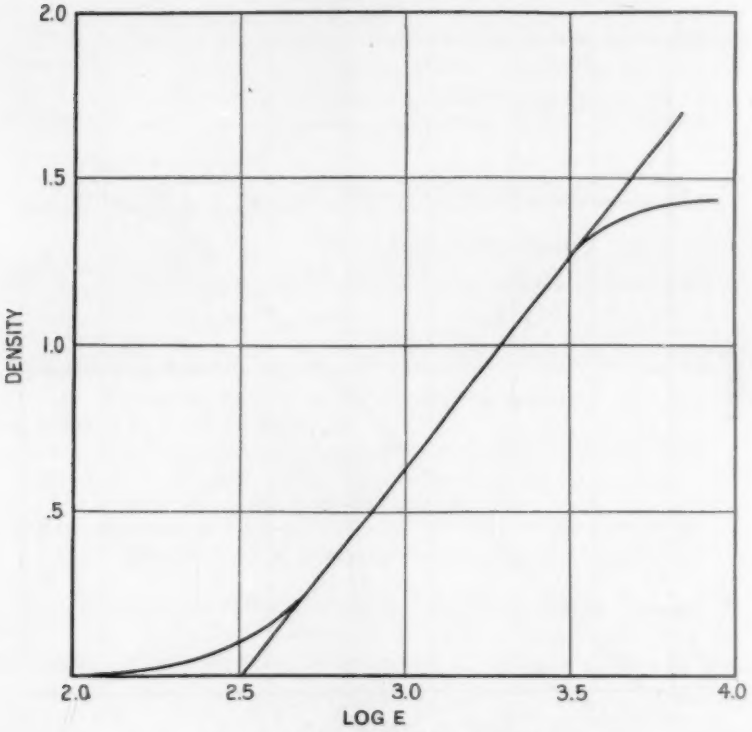
various values of B (plotted on a log scale). The relation between curves A and B, that the sensibility curve is the first derivative of the sensation (response), is a general one,[12] this being true for the corresponding curves of any physical instrument which indicates by some response (scale reading) the magnitude of the applied stimulus.

The data contained in the curves of the three figures (1, 2, and

[12] Nutting, P. G.: *Bull. Bur. Stds.*, vol. v, 1908, p. 266.

3) with the other values mentioned in the tabulation (p. 46) constitute the material from which a complete solution of the tone reproduction problem can be constructed. Having then made certain simplifying assumptions, established a satisfactory system of terminology and symbols, and considered briefly, in a general

FIG. 2.



Characteristic curve of positive material.

way, the problem and the necessary factors involved, let us proceed to the development of the graphic and analytical solutions.

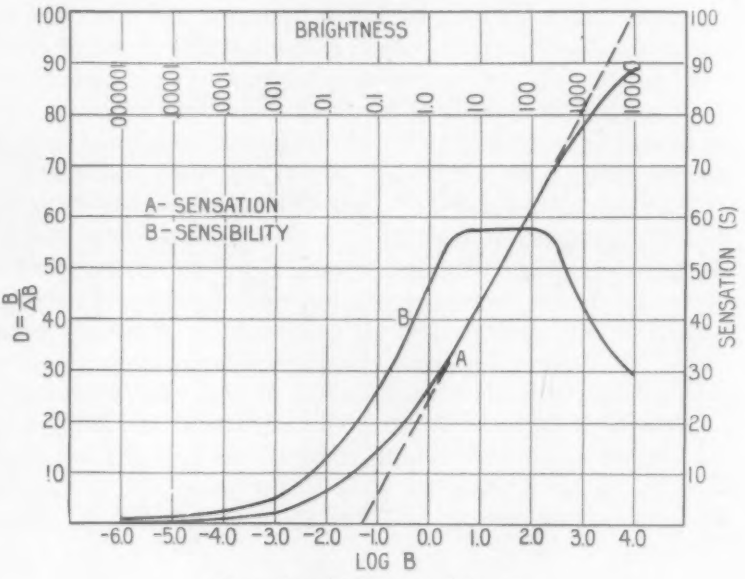
A GRAPHIC SOLUTION.

The graphic solution is presented in Fig. 4, the necessary curves being plotted in the four quadrants designated for reference as *I*, *II*, *III*, and *IV*. For convenience in plotting a double scale along the OX' axis, a separation between the upper and

lower quadrants is made, the two points designated by O being, in fact, identical.

Along the line OX is established a suitable logarithmic scale upon which may be plotted the logarithms of the brightness values for the various areas of the object. Let the points a_o, b_o and c_o represent three typical object-brightness (B_o) values, a being the lowest and c the highest which exist in the object considered. After having located on this scale (log B_o) the various points

FIG. 3.

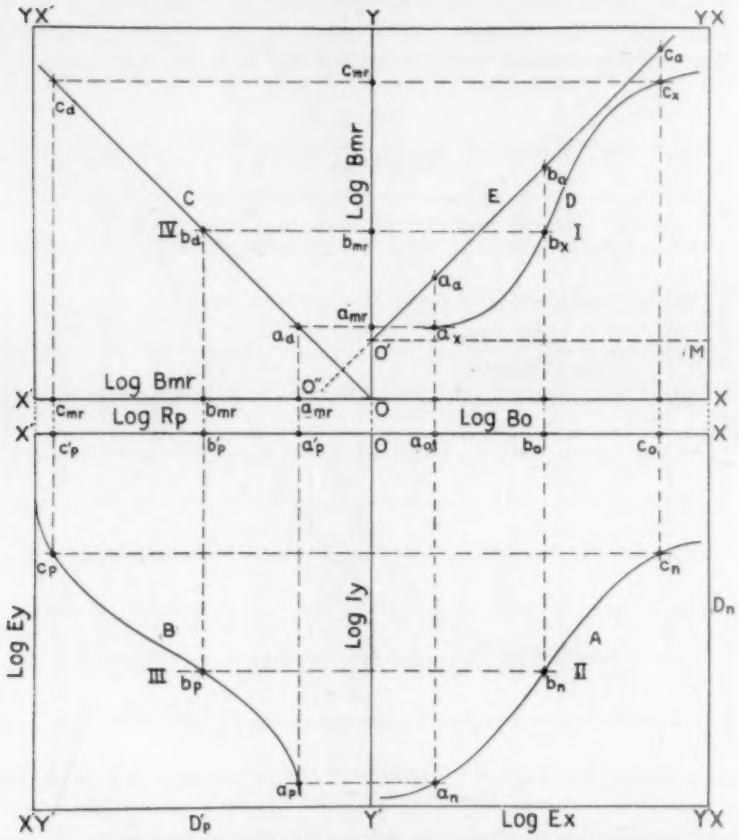


Contrast sensitivity curves of the eye.

representing the brightness values of the object which it is desired to reproduce, the curve A is plotted directly under the log B_o scale, and properly placed in the horizontal direction relative to the points on the log B_o scale. This curve A is the characteristic H and D curve of the sensitive material on which the negative is made. It must be determined by sensitometric methods such that it is a true representation of the characteristic of the negative material when used under the conditions existing in the making of the negative, such conditions including those factors operative in transforming the latent into a real image as well as

the necessary physical condition relative to quality and intensity of the exposing radiation. This characteristic is therefore the curve of effective printing densities as defined and determined in the paper previously mentioned (Jones and Wilsey). Curve *A* is

FIG. 4.



Graphic solution for the objective phase of tone reproduction.

plotted with values of log exposure as abscissæ and densities as ordinates, the log E_x scale being laid off on the line Y', $Y'X$, and the density scale on the line $Y'X$, X.

The density values for the negative include the density of both fog and supporting material as well as of the silver deposit due to the exposure, thus being values of total density. Since the as-

sumption has been made that the deposits are non-selective, it follows that the color-coefficient is unity. It was assumed that the density values are determined under such conditions of illumination (diffuse or specular) that they are true values for the printing process used, contact or projection as the case may be. The unit interval on the log E_x scale must be equal to the unit used in establishing the log B_o and equal also to the unit interval of all log-scales used throughout the solution. The adjustment of the scale of log E_x along the line Y', $Y'X$, depends upon the choice of the negative density value (D_n) by which it is desired to render a given object brightness. For instance, if it be desired to render point a_o, the lowest brightness in the object by a negative density of .20, the scale of log E_x is so adjusted that when curve A is plotted the perpendicular dropped from point a_o will cut the curve at a density value of .20.

The relation between the log B_o and the log E_x scale will now determine the exposure that must be given to the sensitive material on which the negative is to be made in order to obtain the rendition of the chosen brightness value by the desired negative density. In order to compute the exposure time, t_x, however, certain constants of the image forming system used in imaging the object on the sensitive material must be known.

Let the constant K_x be defined as that value by which a given value of object brightness, B_o must be multiplied in order to obtain the value of the illumination, I_x, incident on the negative material at the point where that particular area of object is imaged. K_x is, therefore, the value which satisfies the equation.

$$B_o \cdot K_x = I_x$$

$$\frac{E_x}{I_x} = t_x$$

$$\therefore \quad t_x = \frac{E_x}{B_o \cdot K_x}, \text{ or}$$

$$\log t_x = \log E_x - (\log B_o + \log K_x)$$

In order to compute t_x (K_x being known), it is only necessary to read the values of log B_o and log E_x at the points where any line parallel to OY cuts the two scales and substitute in the equation.

The value of the constant K_x depends on several factors such

as diameter of stop, object and image distances, spectral transmission of the lens material, etc. The evaluation of K_x in terms of these various factors is somewhat complex, and will not be considered at this time.

Now it is convenient to regard the negative produced by the development of the exposed sensitive material (X) as a means of impressing a series of various exposures upon the sensitive material (Y) upon which the positive or print is to be made. The D_n scale must, therefore, be transformed into an inverse scale giving the relative values of the various illuminations which the negative will allow to act upon the material Y during the printing operation. Let I_n be the illumination incident upon the negative during printing, and I_y the illumination transmitted by the negative and therefore incident upon the positive material Y. Let T_n be the transmission coefficient of the negative. T is related to D (Density) by the equation:

$$D = \log \frac{1}{T}$$

and T is defined by the equation,

$$T = \frac{I_1}{I_0}$$

where I_0 = the incident illumination; I_1 = the transmitted illumination.

Hence:

$$I_y = I_n \cdot T_n$$
$$\log I_y = \log I_n + \log T_n$$
$$= \log I_n - D_n$$

Since I_n is a constant, differentiation gives $d \log I_y = -d D_n$. Hence, any interval on the log I_y scale is numerically equal to the corresponding interval on the D_n scale but of opposite sign. Now along the line OY' establish a log scale on which the value of I_y computed from the known values of D_n and some suitably chosen value of I_n may be plotted.

In quadrant III, plot curve B, the characteristic curve of the positive material (Y). This must be determined also under conditions which give the true characteristics of the material as used in making the print from the negative. The abscissæ values of this curve are the densities D'_p while the ordinates are the corresponding exposure values plotted on the scale of log E_y established in a suitable position on the line X', $X'Y'$.

The scale of log E_y must be so adjusted along the line X', $X'Y'$ that the curve B when plotted will occupy the proper position in the vertical direction relative to the position of curve A. The proper position of curve B is determined by deciding by what value of D'_p it is desired to render some chosen value of D_n. For instance, let it be required to render the highest brightness, c_o, of the object by a just perceptible density on the positive. Assuming that the resulting print is to be viewed with an illumination such that the eye is operating in the region of maximum sensitiveness of brightness difference, a deposit differing in brightness by 2 per cent. from the background will be just perceptible. This is equivalent to a transmission or reflection coefficient of 98 per cent., which corresponds to a density of approximately .008. In order to fulfill the requirement, it will be necessary to adjust the scale of log E_y so that when the curve B is plotted a horizontal line drawn through the point where $D'_p = .008$ will cut curve A at c_n, which is also the point where a perpendicular dropped from c_o cuts curve A. The relation between the values of log E_y and log I_y at the points where any line parallel to $X'O$ cuts the two scales determines the exposure necessary to obtain the desired result. Thus:

$$\frac{E_y}{I_y} = t_y$$

or

$$\log t_y = \log E_y - \log I_y.$$

Substituting in this equation the values of I_y and E_y the value of t_y, the exposure time necessary may be determined.

It will be remembered that in order to establish the scale of log I_y a value of I_n was assumed. Since an arbitrary choice of this value, without previous knowledge of the speed of the positive material Y may lead to inconvenient or absurd values of t_y, it may be more logical to omit the establishment of the I_y scale and take the relative value of log E_y and D_n at the points where any horizontal line cuts the respective scales as a means of determining the exposure necessary in making the positive.

Thus:

$$\log t_y = \log E_y - \log I_y,$$

but,

$$\log I_y = \log I_n - D_n,$$

therefore,

$$\log t_y = \log E_y - \log I_n + D_n$$

The corresponding values of log E_y and D_n having been determined, two variables, I_n and t_y, remain, and by choosing a convenient value of t_y the value of I_n (the illumination incident on the negative during printing) necessary to satisfy the equation may be found.

Now let the points a_p, b_p, and c_p be located on curve B at the points where horizontal lines passing through the points a_n, b_n, and c_n intersect curve B, the points a_n, b_n, and c_n having been located at the intersections of curve A with perpendiculars dropped from points a_o, b_o, and c_o.

Along the line OX' lay off a log scale opposite in direction to the scale of log B_o. The scale OX' is that from which the reflection coefficient (R_p) (or transmission coefficient T_p) of the various areas of the positive are determined. The position of this scale along the line OX' is determined by consideration of the values on the D'_p scale and the reflection or transmission coefficient of an area of the positive which has received no exposure. Let R_b (or T_b) be the reflection coefficient of such an area.

The values of D'_p are derived from the measurement of the reflection or transmission coefficient of the various areas of the positive relative to the reflection or transmission coefficients of an unexposed area of the positive material which has received, of course, the same development treatment as the other areas of the positive. These values, therefore, are of relative reflection (or transmission) coefficients. This method of measuring and specifying positive densities is preferable (especially in the case of positives to be viewed by reflected light) from the standpoint of practice, and is the usual procedure in the sensitometry of positive materials. But in order to find the brightness of the various areas of the positive, when observed under a given condition of illumination, it is necessary to know their absolute reflection coefficients. It is necessary, therefore, in order that the values of R_p (or T_p) read from the log R_p scale may be in absolute terms and suitable for the computation of resulting brightness values (B_{mr}) to lay off the values of this scale (log R_p) so as to include the factor R_b (or T_b). The relation between the relative and absolute reflection (or transmission) coefficients is given by

$$R'_p \cdot R_b = R_p$$

or

$$\log R'_p + \log R_b = \log R_p.$$

Where R'_p is defined by the equation

$$\log R'_p = -D'_p.$$
$$\therefore \log R_p = +\log R_b - D'_p$$

The scale on OX' must therefore be so constructed that at corresponding points on the log R_p and log D'_p scales the relation between the values of R_p and D'_p shall be as indicated in this equation.

This equation for the case of a positive material on a transparent base and intended to be observed by transmitted light becomes

$$\log T_p = +\log T_b - D'_p$$

In such cases it is sometimes more convenient to measure the values of D'_p in absolute terms, that is, they already include density of the unexposed area. The term T_b therefore becomes unity, making log T_b zero and the relation is expressed simply as,

$$\log T_p = -D'_p$$

Now the points a'_p, b'_p and c'_p are located on the log R_p scale at the intersections of the perpendiculars through the points a_p, b_p, and c_p, with the line OX'.

The values read from the scale at these points (a'_p, b'_p and c'_p) are the reflection (or transmission) coefficients of the areas on the positive by which the areas of the object represented by the points a_o, b_o and c_o are rendered.

The brightness (B) of a surface in terms of its reflection coefficient (R) and the incident illumination (I) is given by the relation,

$$B = I \,.\, R$$
$$\log B = \log I + \log R$$

Assuming then that the illumination on the positive during observation is I_p the brightness of any given area of the material (objective) reproduction is obtained by the relation

$$\log B_{mr} = \log R_p + \log I_p$$

The brightness of the areas a_p', b_p', and c_p' can, therefore, be computed for any assumed value of the illumination under which the positive is observed or the value of I_p can be computed for any assumed brightness for a given area. On the line OX' establish a log scale such that for corresponding points on this and the log

R_p scale (b_p' and b_{mr}, for instance) the values of log B_{mr} and log R_p will with the assumed value of I_p satisfy the equation

$$\log B_{mr} = \log R_p + \log I_p.$$

Or, if it is desired that any given area of the positive be of the same brightness as the corresponding area of the object, the value of I_p necessary can be computed by the relation.

$$\log B_o = \log B_{mr} = \log R_p + \log I_p,$$
$$\log I_p = \log B_o - \log R_p,$$

where log B_o and log R_p are the values for corresponding points of object and positive such as, for instance, b_o and b_p'. Since the relation between the reflection coefficients of the various areas of the positive may be entirely different from the relation between the brightness values of the corresponding areas of the object, it is in general possible to realize this equality of brightness condition for only one point on the positive. In practice, however, it is found that by proper adjustment of conditions it can be realized throughout a finite range, which in some cases is a considerable proportion of the entire tonal range of the object.

Now in considering the extent to which a given positive observed under given illumination reproduces the subjective impression caused by observation of the object itself, it is necessary to take into account the state of adaptation of the observer's eye not only while viewing the reproduction, but also when looking at the object. The curve which determines the relation between what we shall term the material reproduction and the subjective reproduction is, in the complete graphic solution, plotted in quadrant *IV*, and is referred to as the subjective relative-contrast function. In order to avoid confusion, it will be well for the present to omit consideration of this step in the problem and to complete the first solution for material reproduction, after which a more comprehensible exposition of the subjective phase will be possible.

In order to obtain the reproduction curve, it is necessary to transfer the points a_{mr}, b_{mr}, and c_{mr} to the OY axis. This can be done by simply rotating the log B_r scale about the point O until it coincides with the line OY, but since later a surve (the subjective relative contrast function) will occupy quadrant *IV* it will be better to make use of what may be termed a " dummy " curve (C) in *IV*, this being simply a line making an angle of 45° with the

line OX' and passing through O. Vertical lines through the points a_{mr}, b_{mr}, and c_{mr} intersecting curve D locate the points a_d, b_d, and c_d on this curve and horizontal lines through these intersections locate by their intersection with the line OY the position of the point a_{mr}, b_{mr}, and c_{mr} on this scale. Now the intersections of the horizontal lines through a_{mr}, b_{mr}, and c_{mr} (on line OY) with the vertical lines through a_o, b_o, and c_o determine the points a_x, b_x, and c_x which, when connected as shown, established the shape and position of the reproduction curve D (in I). This affords a graphic representation of the relation between the brightness factors of the object and those of the material reproduction (the illuminated positive). Now, though the point on the log B_{mr} scale (on line OY) where log B_{mr} is equal to the value of log B_o read at the point O (on line OX) draw a line parallel to OX. In the figure this is represented by the broken line $O'M$. This line is the absolute x axis of the reproduction curve D while the line $O'Y$ is the corresponding y axis, O' being the absolute origin. The line OX can be retained as the absolute axis by displacing the point of intersection of the dummy curve C (IV) in the proper direction along the X axis (line X', O, X) by a distance equal to OO'. (In the case shown in Fig. 4 this point would be to the left of O at O''.) In practice, however, such procedure usually results in the displacement of the reproduction curve, D, in the vertical direction by an inconvenient amount and location of the new position of the absolute axis as indicated is usually more convenient. In some cases this method may result in the point O' falling outside the limits of the available coördinates, in which case its location is best indicated by a dimension line carrying a numerical indication of its position relative to the apparent axis OX.

Now a straight line drawn through O' and making an angle of 45° to the line $O'M$ is the curve E, of absolute reproduction, this term being used to denote an exact reproduction in the material reproduction of both the brightness and contrast of the object. For any point on the reproduction curve, D, the magnitude of the departure from an exact reproduction of brightness is given by the length of the perpendicular line limited by the two curves D and E and drawn through the point considered; while the relation of the slopes (first derivatives) of the curves at corresponding points (b_a and b_x, for instance) determine the magni-

tude of the departure from exact reproduction of the contract in the object at the point (b) considered.

The fact that the curve E is the curve for the exact reproduction of brightness follows from the construction which is such that for any point on this curve log B_o is equal to log B_{mr}, thus satisfying the necessary condition that $B_o = B_{mr}$. The fact that a given brightness interval of the object is represented by the same brightness interval on the curve E indicates that the contrast of the object has been exactly reproduced. A straight line at 45° to the axis is the necessary condition for exact contrast reproduction, while for exact reproduction of brightness this line must pass through a certain specified point on the log B_{mr} scale.

From the position of the curve E relative to D (the reproduction curve), it is possible to determine quantitatively the magnitude of the departure from the condition of exact brightness reproduction. The most convenient method of expressing the magnitude of this departure is by use of the ratio of the brightness of the object to the corresponding brightness of the reproduction, which ratio will be designated by the symbol ΔB.

$$\Delta B = \frac{B_o}{B_{mr}}, \text{ or}$$

$$\log \Delta B = \log B_o - \log B_{mr}$$

Hence, if on the log B_{mr} scale (line OY) the values for any pair of corresponding points on the curves E and D (b_a and b_x, for instance) be read, ΔB can be determined. Since for any point on E, log B_o = log B_{mr}, the value of log B_{mr} can be substituted for log B_o. For instance, consider the pair of corresponding points a_x and a_a

$$\log \Delta B = \log B_o \text{ (at } a_o) - \log B_{mr} \text{ (at } a_x),$$

$$\text{and } \log B_o \text{ (at } a_o) = \log B_{mr} \text{ (at } a_a),$$

$$\therefore \log \Delta B = \log B_{mr} \text{ (at } a_a) - \log B_{mr} \text{ (at } a_x).$$

It also follows since the length of the line $a_a\ a_x$ is given by

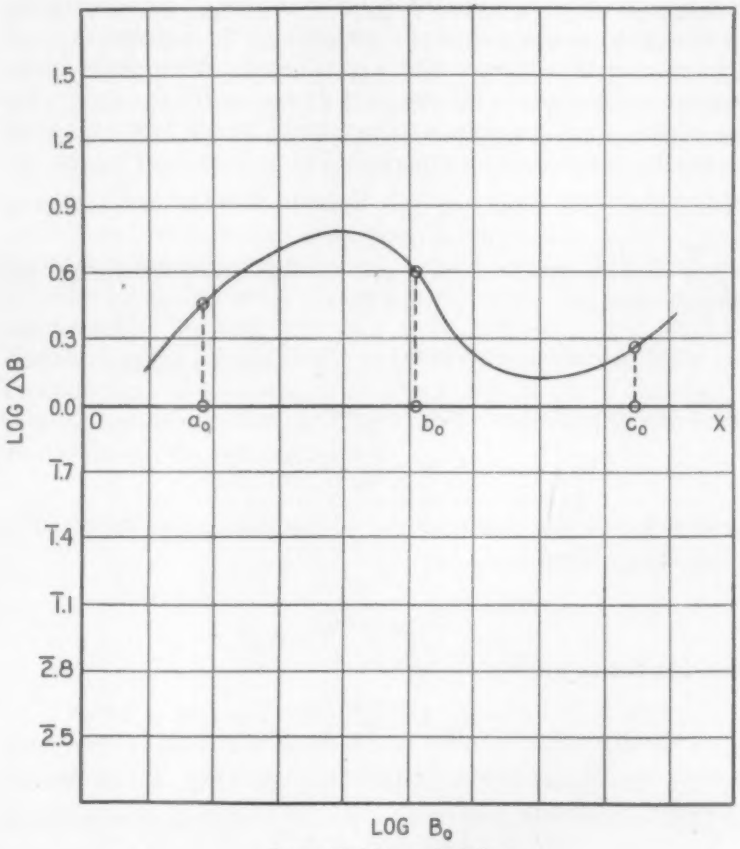
$$a_a\ a_x = \log B_{mr} \text{ (at } a_a) - \log B_{mr} \text{ (at } a_x).$$

that log ΔB = the line $a_x\ a_a$.

Hence in order to plot the curve of brightness deviation in terms of its logarithm, it is only necessary to use as ordinates the lengths of the perpendiculars lying between the two curves D and E. For the sake of convenience and the avoidance of confusion due to a multiplicity of lines, this curve is not plotted in Fig. 4,

but is transferred to Fig. 5, the log B_o scale being a duplicate of that in Fig. 4 and the ordinates the values of log ΔB. The line OX passing through the point log $\Delta B = o$ ($\Delta B = 1.0$) is the line of no deviation, hence the axis of exact brightness reproduction. In plotting the curve of log ΔB (Fig. 5) the sign of the

FIG. 5.



Curve of brightness deviations.

quantity log ΔB must be considered. A point lying below the curve E (Fig. 4) will be represented in Fig. 5 by a point above the line OX and *vice versa*, a value of log ΔB greater than $o.o$, indicating that ΔB is greater than unity, and hence that B_o is greater than B_{mr}, while a value of log ΔB less than $o.o$ shows that B_o is less than B_{mr}.

ANALYTICAL CONSIDERATIONS.

Let us now apply the method of the differential calculus to the functions plotted in Fig. 4. Such treatment is especially useful in a determination of the contrast relations existing between the various elements. If at any point the ratio of some small increment ΔY (in the direction of the Y coördinate) to the corresponding increment ΔX (in the direction of the X coördinate) be computed the value obtained is a measure of the average slope of the curve over the distance (ΔX) considered. When these increments are reduced to the infinitesimal dy and dx the ratio gives the value of the slope at a point on the curve. Hence, if the slope or gradient be designated by the symbol G, it is defined by the expression $G = \frac{dy}{dx}$. Applying this then to the curves of Fig. 4, the following expressions are obtained.

The density gradient of curve A, the characteristic of the negative materials (X), is given by

$$G_n = \frac{d\,D_n}{d\,\log\,E_x}$$

Since $d\,\log\,E_x = d\,\log\,B_o$ this becomes

$$G_n = \frac{d\,D_n}{d\,\log\,B_o}$$

Likewise for B, the characteristic of the positive material (Y), the density gradient is,

$$G_p = \frac{D'_p}{d\,\log\,E_y}$$

While for the reproduction curve D

$$G_{mr} = \frac{d\,\log\,B_{mr}}{d\,\log\,B_o}$$

From the construction of the diagram (Fig. 4), it will be seen that

$$d\,\log\,E_y = -d\,D_n$$

and

$$d\,\log\,B_{mr} = -d\,D'_p = d\,\log\,R_p$$

$$\therefore G_n = -\frac{d\,\log\,E_y}{d\,\log\,B_o}$$

and

$$G_p = -\frac{d\,\log\,B_{mr}}{d\,\log\,E_y}$$

$$G_n \times G_p = -\frac{d \log E_y}{d \log B_o} \cdot -\frac{d \log B_{mr}}{d \log E_y} = \frac{d \log B_{mr}}{d \log B_o} = G_{mr}$$

$$\therefore G_n \cdot G_p = G_{mr}$$

Now for exact reproduction of contrast, it is necessary that $G_{mr} = 1.0$ and the condition fulfilling this requirement is that the product of the gradient (or slope) of the negative characteristic by the gradient of the positive characteristic shall be equal to unity. If $G_n \cdot G_p$ is greater than unity, a given brightness difference in the object ($d \log B_o$) is rendered in the positive by a brightness difference ($d \log B_{mr}$) greater than that existing in the object and hence the contrast is increased or the contrast scale is expanded. On the other hand, if $G_n \cdot G_p$ is less than unity it indicates that the brightness difference in the positive is less than the corresponding difference in the object ($d \log B_{mr} < d \log B_o$) and it follows that the contrast is decreased, that is, the contrast scale is compressed. Turning now to a consideration of the most convenient method of showing graphically the departure from exact reproduction of contrast, it is found that a curve showing the relation between B_o and the slope (G_{mr}) of the reproduction curve, D, fulfills all the requirements

$$G_e \text{ (Curve } E) = 1.0 \text{ by construction}$$

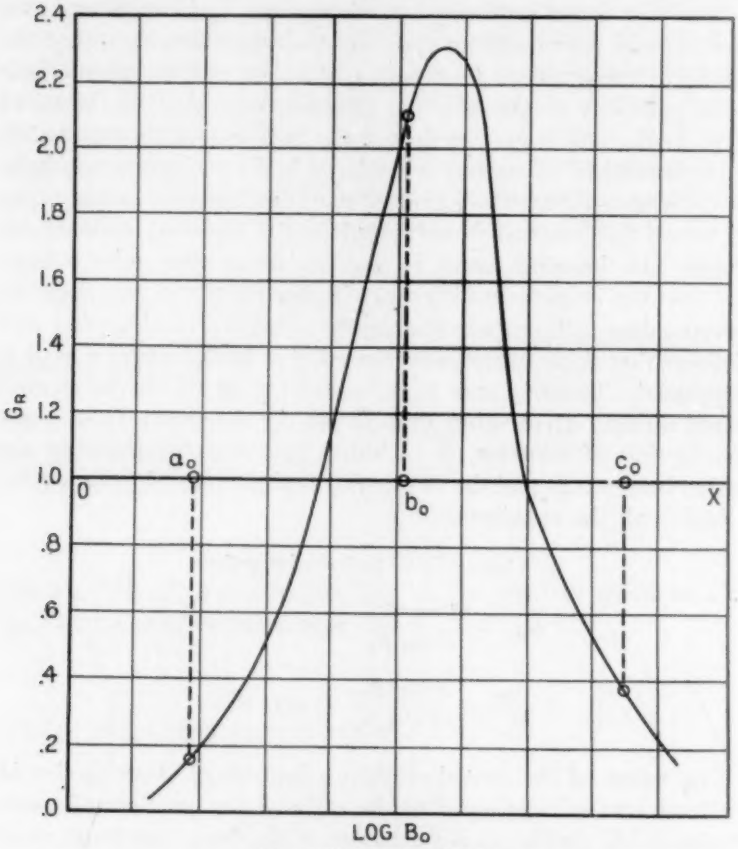
$$G_{mr} = \frac{d \log B_{mr}}{d \log B_o} \text{ (Curve } D)$$

$$\therefore \frac{G_{mr}}{G_e} = \frac{d \log B_{mr}}{d \log B_o} \text{ (Curve } D)$$

The value of the first derivative of curve D at any point is, therefore, numerically equal to the ratio of the gradient of curve D to that of E, and hence is a measure of the departure from exact contrast reproduction. In Fig. 6 is plotted the value of $\frac{d \log B_{mr}}{d \log B_o}$ (for curve D) as a function of B_o. The log B_o scale is again a duplicate of that in Fig. 4, and the ordinates are gradient values. The condition that $G_{mr} = 1.0$ is that for exact contrast reproduction, and hence the line OX ($G_{mr} = 1.0$) is the curve of exact contrast reproduction. Points lying above this line ($G_{mr} > 1.0$) indicate an increased contrast in the positive while points below ($G_{mr} < 1.0$) correspond to a diminished contrast. In case a given

difference of brightness ΔB_o in the object is rendered by a greater brightness difference ΔB_{mr} in the reproduction, the contrast scale is said to be expanded while the opposite condition is expressed as

FIG. 6.



Curve of contrast deviations.

a compression of the contrast scale. These conditions may be expressed mathematically, thus,

1. Increased contrast (Expansion of contrast scale).
$$G_{mr} > 1.0$$
2. Exact contrast reproduction (Normal contrast).
$$G_{mr} = 1.0$$
3. Diminished contrast (Compression of contrast scale).
$$G_{mr} < 1.0$$

In dealing with the straight line portion the gradient values are constant, and hence are direct measures of the contrast reproduction in such regions.

Thus far, no assumption has been made relative to the shape of the curves A and B, the treatment having been of a general nature. In practice it is found that both of these curves may, within the limits of observation, be straight lines over a considerable portion of their lengths. The tangent of the angle which such straight portion makes with the log E axis is designated by the symbol γ, and is equal to the gradient $\left(\frac{d\,D}{d\,\log E}\right)$ at any point on the straight line portion. The gradient being constant throughout such straight portions, it is convenient when dealing with tone reproduction by such portions alone to replace the values of gradient by those of gamma. The relation thus obtained is

$$\gamma_n \cdot \gamma_p = \gamma_{mr}$$

This it may be noted is the relation deduced by Porter and Slade (*loc. cit.*) which is a special case of the more general relation between the gradient values. The special case is, of course, simpler to deal with and is applicable when the entire reproduction can be obtained by use of the straight line portions, which frequently occurs when the positive is made to be viewed by transmitted light (transparencies, etc.). In the case of a positive to be viewed by reflected light, it is usually necessary to utilize the entire scale of the positive material, including the curved portions as well as the straight line, and in such cases the special relation ($\gamma_p \cdot \gamma_n = 1.0$, for exact contrast reproduction) is practically useless, it being necessary to employ the more general form, $G_p \cdot G_n = 1.0$.

For that brightness range of the object which can be rendered by the use of deposits in the negative and positive situated on the straight line portion of the characteristic curves of both materials, the above relation may be used. Stating this relation in words, we have for the most general case where the gradient is variable from point to point, that the product of the gradient of the negative by the gradient of the positive is equal to the gradient of the reproduction curve. This applies only, of course, to the gradient values determined at the corresponding points on the three curves, corresponding points being defined as any three points related to each other as the point b_n, b_p, and b_x, Fig. 4. Or, for the straight

line portions where gradient is constant and replaceable by gamma, we have that the product of the gamma of the negative by that of the positive is equal to that of the reproduction curve. It may be of interest to note at this point that this is precisely the same relation as that derived by the author in collaboration with Mr. Wilsey (*loc. cit.*), when applying this general method to the problem of measuring the color coefficient photographic deposits. And, since, for exact contrast reproduction, the slope (γ) of the reproduction curve must be unity, the necessary condition is expressed by

$$\gamma_n \cdot \gamma_p = 1.0$$

or

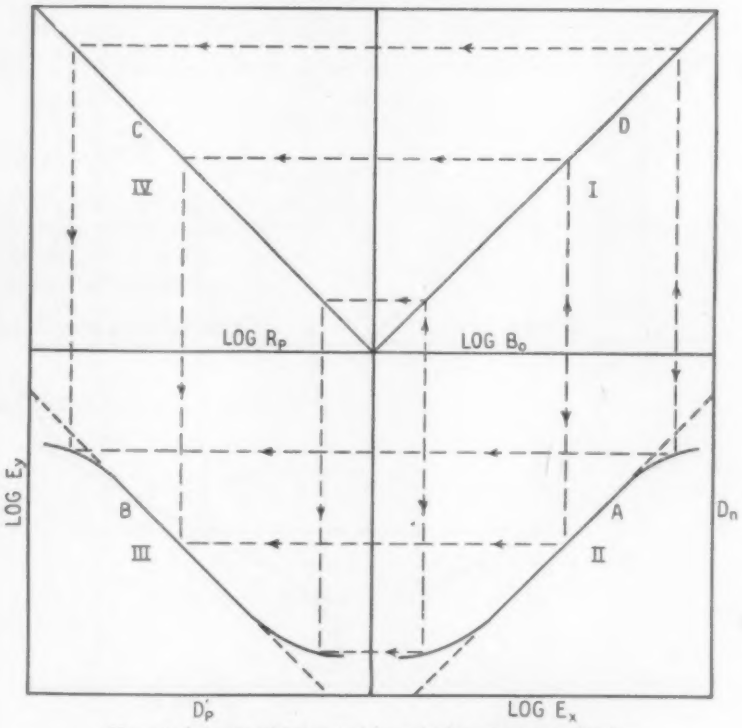
$$\gamma_n = \frac{1}{\gamma_p}$$

It should be borne in mind, however, that this relation holds only for the straight line portion of the curves, while the relation between the values of the differentials G_n, G_p, and G_{mr} is perfectly general and valid for any point regardless of the shape of the curves.

From a complete knowledge of the characteristics of the negative and positive materials, it is now possible to compute the quality of reproduction obtainable. It is also evident from the construction of Fig. 4 if only one of these functions is known, that that of the other can be obtained either graphically or by analytical methods provided an assumption as to the shape of the reproduction curve, D, be made. For instance, if exact reproduction of contrast be desired and a given negative material is to be used, it is evident that curve D must become a straight line having a gradient of unity ($G_{mr} = 1.0$). The shape of the positive characteristic necessary can now be determined. In Fig. 7 is shown the construction which determines this and the resulting shape in case the negative material has the characteristics indicated by curve A. Curve B is the necessary form of the function $D_p = f$ (log E_v). It will be noted that this is of the same general shape as the " reciprocal curves " obtained by Mr. Renwick, which, however, cannot be realized in practice. While Mr. Renwick does not explain the method by which he arrived at the shape of his reciprocal curves, it was undoubtedly by a method somewhat similar to that presented in this paper; at least he arrives at the same general conclusion.

In a similar manner it is possible to determine the required shape of the negative characteristic ($D_n = f$ (log E_x) in order to obtain any desired reproduction with a given positive material. The construction for this is shown in Fig. 8, exact reproduction of contrast being assumed with the positive material represented by the curve B. Figs. 7 and 8 serve to show the limita-

FIG. 7.



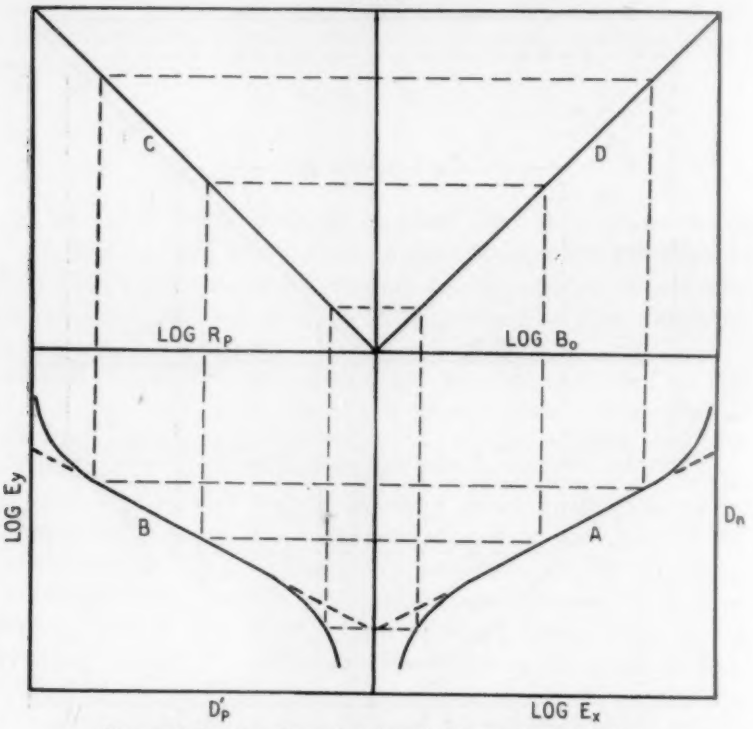
Characteristic of positive material required for exact reproduction.

tion of the photographic process in the exact reproduction of contrast, and since the method of construction must be obvious after the detailed discussion of Fig. 4, it will be unnecessary to discuss this further.

Another application of the method which may be mentioned is to the problem of finding the extent to which a negative must be developed in order to render any specified range of brightness values of the object on the straight line portion of the positive

material. In Fig. 9 assume that the range between a_o and b_o on the log B_o scale is to be rendered on the straight line portion of the positive material (Curve B). Locate the point a_p, b_p at the limits of the straight line portion of curve B, and find the positions of points a_n and b_n at the intersections of the vertical and horizontal dotted lines as shown. The line through a_n and b_n is the

FIG. 8.



Characteristic of negative material required for exact reproduction.

negative characteristic, A, required, the gradient of which is given by the relation,

$$G_n = \frac{d\,D_n}{d\,\log\,E_x}$$

or since we are dealing only with the straight line portions for which G_n is constant, $G_n = \gamma_n$

$$\gamma_n = \frac{\Delta\,D_n}{\Delta\,\log\,E_x} = \frac{\Delta\,D_n}{\Delta\,\log\,B_o}$$

Where

$\Delta D_n = D_n$ (at b_n) $- D_n$ (at a_n) = Density Latitude (DL_n)

$\Delta \log E_x = \log E_x$ (at b_n) $- \log E_x$ (at a_n) = Exposure Latitude (EL_n)

$\Delta \log B_o = \log B_o$ (at b_o) $- \log B_o$ (at a_o)

$\Delta D_n = -\Delta \log E_y$

Further

$$\gamma_p = \frac{\Delta D'_p}{\Delta \log E_y} = -\frac{\Delta \log R_p}{\Delta \log E_y}$$

and

$$\gamma_{mr} = \frac{\Delta \log B_{mr}}{\Delta \log B_o}$$

Where

$\Delta D'_p = D'_p$ (at a_p) $- D'_p$ (at b_p) = Density Latitude (DL_y)

$\Delta \log E_y = \log E_y$ (at a_p) $- \log E_y$ (at b_p) = Exposure Latitude (EL_y)

$\Delta \log R_p = -\Delta D'_p$

$\Delta \log R_p = \Delta \log B_{mr}$

As shown previously,

$$\gamma_n \cdot \gamma_p = \gamma_{mr}$$

and for exact reproduction of contrast,

$$\gamma_{mr} = 1.0$$

Now from the above relations, it can be shown in the case plotted in Fig. 9 that

$$\gamma_n = \frac{\Delta \log E_y}{\Delta \log B_o} = \frac{\text{Exposure Latitude of Positive Material.}}{\text{Brightness Range Assumed.}}$$

and that

$$\gamma_{mr} = \frac{\Delta D'_p}{\Delta \log B_o} = \frac{\text{Density Latitude of Positive Material.}}{\text{Brightness Range Assumed.}}$$

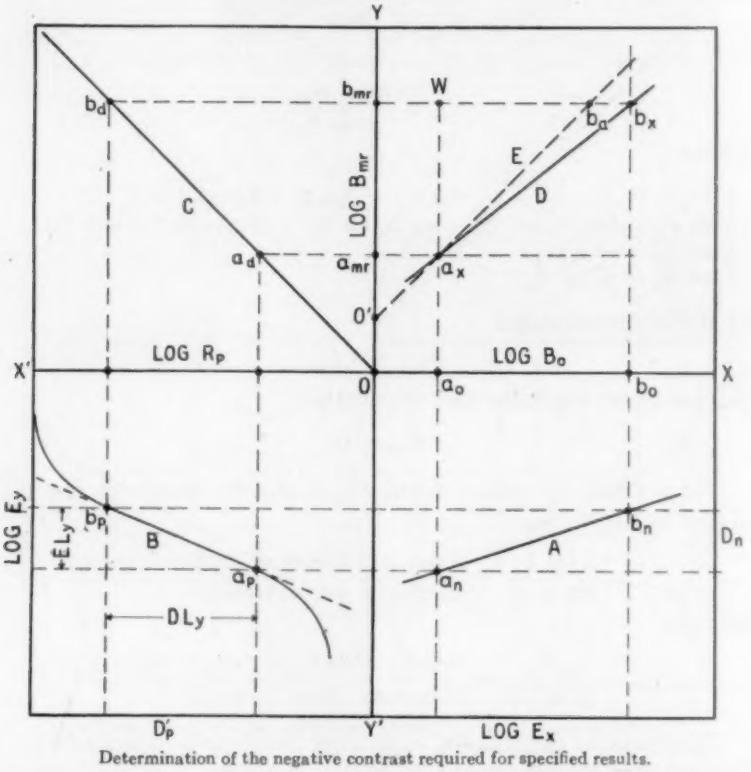
Also that in general the maximum brightness range of object that can be exactly reproduced is given by $\Delta \log B_o = \Delta D'_p$ (Density Latitude of Positive Material).

These statements assume that the exposure latitude of the negative material is equal to or greater than that of the positive material.

The writer wishes at this point to call attention to the fact that this conclusion, $\Delta \log B_o$ (Max. exactly reproducible) $= \Delta D'_p$, is the same as that drawn by Porter and Slade

(*loc. cit.*) in their recent publication, in which they state that such conclusion is at variance with that reached by the present author, who, in collaboration with Mees and Nutting, published some time ago a paper entitled "The Sensitometry of Photographic Papers" (*Phot. Jour.*, Vol. n. s., 38 (1914) p. 342). This paper, as indicated by its title, dealt with methods for the determination of the

FIG. 9.



Determination of the negative contrast required for specified results.

sensitometric constants of photographic printing papers, and did not pretend to deal with the problem of tone reproduction. A comparison of the characteristics of a negative material and a printing paper was made only for the sake of emphasizing the marked difference between them. Quoting the sentences in question we state: "But the maximum values of latitude met with in papers is of the order of .75 in log *E* units, or 1 to 5.6 in exposure

units. The paper then will only render correctly a range of brightness ranging from 1 to 5.6; hence it is obvious that in order to render a *negative* having a range any wider than 1 to 5.6 in *transmission* it is necessary to utilize portions of the characteristic curve lying outside the 'latitude' of the paper and thus depart from correct proportional rendering." It may be possible that the use of the word "brightness" in the first phrase (which was used as specifying the intensity factor of the light permitted by the negative to act upon the paper during printing) may have been misinterpreted. In the next sentence, however, it is specifically stated that a negative "having a range wider than 1 to 5.6 in *transmission*" was being considered. The word "transmission" should certainly have corrected any misapprehension arising from our use of the word "brightness." Moreover, in the following sentence of our paper, it is again clearly stated that the point under consideration is the "range of densities in the negative that can be correctly rendered," with no mention of the object brightness represented by such negative densities.

Returning again to further consideration of Fig. 9, it is evident if the range of brightness values ($\Delta \log B_o$) is greater than the density latitude (DL_y) of the positive material being used that it will be impossible to reproduce exactly the contrast of the object over the entire range, $\Delta \log B_o$.

However, it is possible to compress this tone scale of the object so that it can be proportionately rendered on the straight line of the positive material. Proportional rendering is defined by the relation, $d \log B_o = k \, . \, d \log B_{mr}$, where k is a constant known as the proportionality factor.

$$k = \frac{d \log B_o}{d \log B_{mr}} = G_{mr}$$

or

$$k = \gamma_{mr} \text{ (For straight line portion).}$$

γ_{mr} may, therefore, be considered as the proportionality factor indicating the magnitude of the expansion or compression of the contrast scale. Thus, if $\gamma_{mr} = .5$ it indicates that a given brightness interval of the object has been compressed to one-half of its value in the reproduction, that is, the contrast has been decreased by one-half. The same applies to an expansion of the scale resulting in an increased contrast in the reproduction, the value

of γ_{mr} being again the proportionality factor. This, then, may be defined as that value by which a given brightness interval in the object must be multiplied in order to obtain the corresponding brightness interval in the reproduction.

It is evident from an inspection of Fig. 9 that the range of object brightness values which can be reproduced in correct proportion is limited only by the exposure latitude (EL_x) of the negative material. Since a negative material may have a latitude of 1 to 128 (in exposure units) or even more, it is evident that the great majority of objects may be rendered proportionally on the straight line portion, for measurements show that the contrast range seldom exceeds this value (1 to 128).

The applications of the methods outlined to practical problems are too numerous to mention in detail at this time. However, a specific example, Fig. 10, is shown. This illustrates the reproduction resulting from the use of obtainable negative and positive materials, the characteristic curves of which have been carefully determined by sensitometric measurements in this laboratory. The data, essential to this discussion, relative to the materials are as follows:

The negative material:

EL_x (Exposure latitude) > 2.0 (in log E).

$\log i = \bar{2}.5$

$\gamma_\infty > 1.00$

The positive material (a developing-out paper).

E_s	(Standard Exposure)	= 100,000 (m.c.s.)
γ_∞		= 1.34
EL_y	(Exposure Latitude)	= .77 (in log E)
ES_y	(Exposure Scale)	= 1.50 (in log E).
DL_y	(Density Latitude)	= 1.06
DS_y	(Density Scale)	= 1.43
D_{max}	(Maximum Density)	= 1.45
R_b	(Reflecting power of fog strip)	= .80

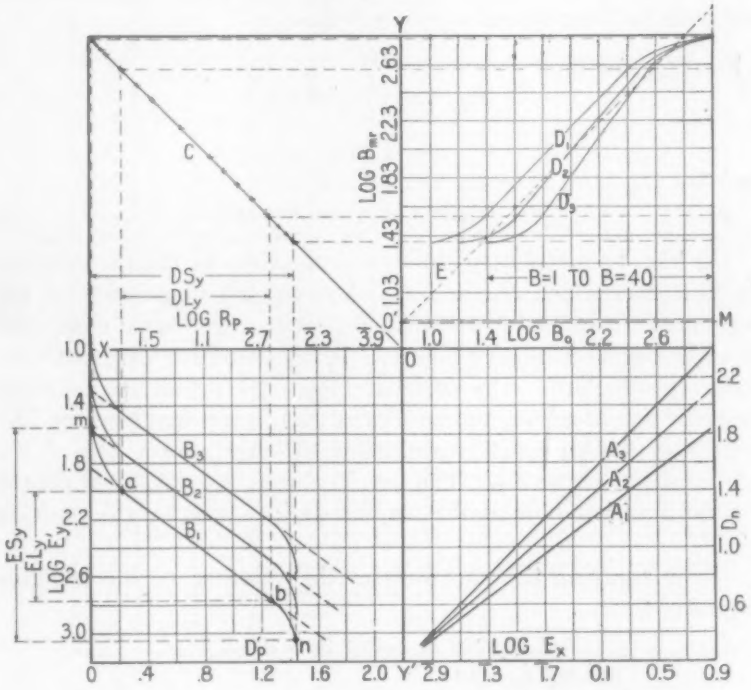
Let it be assumed that the highest object brightness is 1000 (apparent meter candles), and that this brightness is to be rendered in the positive by a just perceptible density ($D = .01$ (approximately), $R_p' = .02$).

In order to illustrate the effect of the contrast (γ) to which the negative is developed upon the quality of the resulting repro-

duction, three different negative characteristics are plotted differing only in the value of gamma. The gamma values chosen are for A_1, $\gamma_n = .75$; for A_2, $\gamma_n = .87$; and for A_3, $\gamma_n = 1.00$.

The three curves B_1, B_2, and B_3 represent the characteristic of the positive material, these being exactly similar in shape but plotted in different position so that the condition of a just per-

FIG. 10.



Objective reproduction obtainable with specified materials and conditions.

ceptible density for the highest light may be fulfilled in all cases. The values on scale of log E'_y are arbitrary and a constant which differs for each of the curves B_1, B_2, and B_3 is applied in order to determine the value of log E_y, from which the absolute value of printing exposure necessary may be computed, the relation being $\log E'_y + C = \log E_y$.

Curve C is the dummy used for transferring the points on the scale of log R_p to the log B_{mr} scale. Under certain conditions

(previously specified) this curve becomes the actual subjective relative-contrast function. The points on this curve merely illustrate the way in which the construction points are located and apply to the construction of Curve D_1. The curves D_1, D_2, and D_3 are reproduction curves obtained by the graphic solution as previously outlined, D_1 being that obtained by the use of A_1 and B_1, etc. Since the positive material has a straight line portion, each reproduction curve is straight over part of its length. The gamma relation corresponds to the expression $\gamma_p \cdot \gamma_n = \gamma_{mr}$.

Therefore for D_1

$$\gamma_{mr} = 1.34 \cdot .750 = 1.01$$

for D_2

$$\gamma_{mr} = 1.34 \cdot .91 = 1.17$$

and for D_3

$$\gamma_{mr} = 1.34 \cdot 1.00 = 1.34$$

In Fig. 11 are plotted the first derivatives of the three reproduction curves D_1, D_2, and D_3 showing the magnitude of the departure from exact contrast rendering for each case, the straight line at $G_{mr} = 0$ (Fig. 11) being the curve of exact contrast reproduction. The curve E (Fig. 10) is the line of exact contrast reproduction, and so located as to represent also the best approximation to exact reproduction of brightness in case of the reproduction curve D_2. The log B_{mr} scale is established on the assumption that I_p is of the magnitude indicated by the position of O'.

Now applying the equation for the value of t_x, the negative exposure time,

$$\log t_x = \log E_x - (\log B_o + \log K_x).$$

Let $\log B_o = 2.6$

Then $\log E_x = 0.5$

And assume as a value for the constant of the image forming system

$$K_x = .01, \quad \log K_x = \bar{2}.0$$

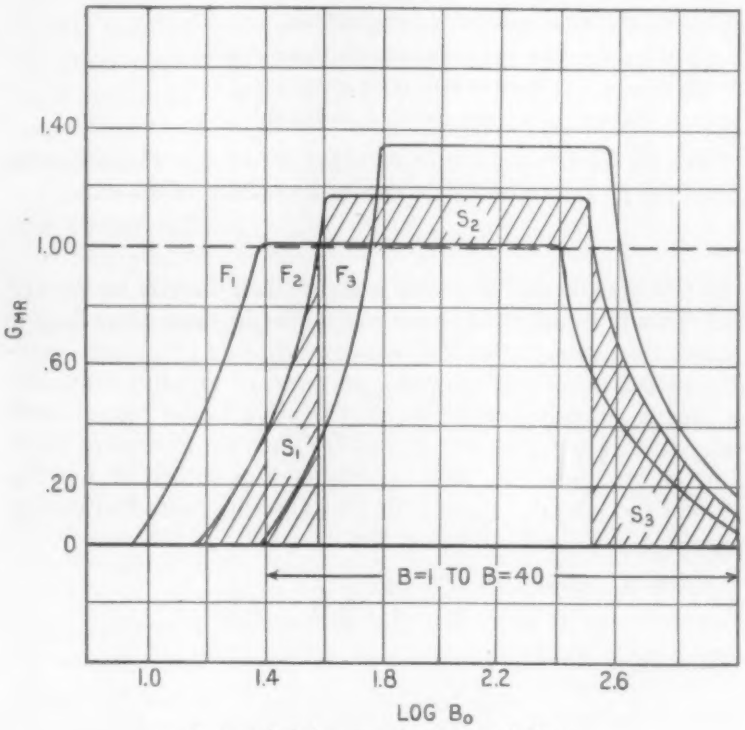
Solving we obtain

$$t_x = .0126 \text{ sec.}$$

This then is the time necessary in exposing the negative material.

The standard exposure, E_s, is defined (Jones, Mees, and Nutting, *l. c.*) as that exposure in meter-candle seconds which will just print through a density of 2.0. Since a density of 2.0 transmits .01 of the incident illumination it follows, in the present case, that an exposure of .01 × 100,000 mcs. or 1000 mcs. will produce a just perceptible deposit on the positive material used.

FIG. 11.



Contrast deviations occurring in curves in Fig. 10.

Therefore at the point where

$$\log E'_y = 1.55,\ \log E_y = \log 1000 = 3.0$$
$$1.55 + C = 3.0$$
$$\therefore C_1 = 1.45$$

Likewise,

$$C_2 = 1.73$$
$$C_3 = 2.01$$

Now from the equation (p. 53) giving the printing exposure necessary,

$$\log t_y + \log I_n = \log E_y + D_n$$

Where $D_n = 1.4$

$$\log E_y = 2.0 + 1.45 = 3.45$$

$$\therefore \log t_y + \log I_n = 3.45 + 1.4 = 4.85$$

$$\text{or } t_y \cdot I_n = 70{,}800$$

Hence, if $I_n = 1000$ m. c.

For negative A_1, $t_y = 70.8$ sec.

Inserting values of $C_2 + C_3$ we obtain

For negative A_2, $t_y = 135$ sec.

and for A_3, $T_y = 250$ sec.

Since R_b for the paper used is .8, $\log R_b = \bar{1}.90$. Therefore the scale of $\log R_p$ is so established that at any point on the scale,

$$\log R_p = \bar{1}.90 - D'_p$$

In this case the $\log B_{mr}$ scale is established directly on the OY axis. This is found to be more convenient in some cases than to establish this scale on the OX' axis as indicated previously, especially when it is desirable to make the curve of absolute reproduction occupy some particular position relative to the reproduction curve. In this case the curve E was drawn in the desired position, and from the point O' thus established the values of $\log B_{mr}$ necessary to make the curve E that of absolute reproduction was determined, the condition being that

$$\log B_{mr} \text{ (at } O') = \log B_o \text{ (at } O)$$

$$\log B_o \text{ (at } O) = .8 = \log B_{mr} \text{ (at } O').$$

Now from the equation,

$$\log I_p = \log B_{mr} - \log R_p$$

it is possible to find the value of I_p which is necessary to illuminate the positive to satisfy the relation between the $\log R_p$ and $\log B_{mr}$ scales as established.

The point on the $\log B_{mr}$ scale, for instance, corresponding to the point where $R_p = \bar{2}.3$ is $\log B_{mr} = 1.23$.

$$\therefore \log I_p = 1.23 - (\bar{2}.3)$$

$$2.93$$

$$I_p = 851. \text{ (meter candles)}$$

Now, with this illumination on the positive obtained by use of negative A_2 the material reproduction will be as indicated by the curve D_2. In the region lying below the line E the areas will be less bright than the corresponding areas of the object, while in those above the contrary will be the case.

By decreasing the illumination the curve E can be made to coincide with the straight line portion of reproduction curve D_1, and much better brightness reproduction obtained for that particular positive in the middle tones, although the departure in the highlights will be greater than for the curve D_2 with the illumination specified. In practice it is not necessary to obtain exact reproduction of brightness since the eye is an organ of variable sensibility, and a low actual brightness may excite the same sensation as one of high value if the adaptation level of the eye be of the proper value.

The location of the points m and n (Fig. 10) should be mentioned at this point. They are the points which limit the scale of the positive material, Y, and are located at the points on the curve of that material where the term $\frac{D_p}{d \log E_y}$ has a certain assumed value. The value assumed previously was .2 and occurs in the particular case of the printing paper used in this illustration at the points where $D = .01$ and $D = 1.44$. The points a and b are located at the extremities of the straight line portion, and their positions determine the values of the exposure latitude, EL_y, and the density latitude, DL_y. Since the gradient, G_{mr}, of the reproduction curve is equal to the product of G_n and G_p, it follows that the gradient of the reproduction curves at points corresponding to m and n will depend on the value of G_n, being greater for high values of G_n and *vice versa*. Practically, however, it many be considered that the scale of the reproduction curve is limited by the points corresponding to m and n as shown by the dotted construction, although in extreme cases exceptions to this rule may be necessary. Likewise the latitude of the reproduction curve may be considered as limited by the points corresponding to a and b. According to this it is evident from the construction that the following relation exists:

Defining as follows:

Object Latitude (OL) = Range of brightness values of the

object rendered on the straight line portion of the reproduction curve.

Object Scale (OS) = Range rendered on scale of reproduction curve.

$$OL = \frac{EL_y}{\gamma_n}$$

$$OS = \frac{ES_y}{\gamma_n}$$

Further if,

BL_{mr} = Brightness Latitude of the Reproduction.
BS_{mr} = Brightness Scale of the Reproduction.

Then:

$$BL_{mr} = DL_y$$
$$BS_{mr} = DS_y$$

It may be of interest to tabulate some of the actual values obtained in this curve.

TABLE II.

Negative	γ_n	γ_{mr}	OL	OS
A_1	.75	1.01	1.03	2.00
A_2	.87	1.17	.89	1.73
A_3	1.00	1.34	.77	1.50

Other useful relations may be desired, but since their importance depends upon the particular problem being dealt with, further consideration will not be given them at this time.

Turning now to the derivatives plotted in Fig. 11, their interpretation will be considered briefly. By integrating the area inclosed by each curve and the line of G_{mr} equal to zero, the mean value of gradient over the entire scale of object brightness rendered can be determined. These values are tabulated in column B (Table III).

TABLE III.

Negative	γ_n	B	C	D
A_1	.75	.71	.30	.25
A_2	.89	.83	.37	.32
A_3	1.00	.95	.45	.48

The mean deviation from the line of exact contrast reproduction can be obtained by integrating the partial areas as indicated by the shaded areas (S_1, S_2, and S_3) which apply to curve F_2, adding the values thus obtained together and dividing by the

value of OS. The mean deviations thus determined are given in column C (Table III).

The deviations thus obtained apply, of course, to different ranges of brightness in the object. However, if it is desired to determine the mean deviation from $G = 1.00$ for a given object having a fixed contrast, it is only necessary to limit the areas considered to the specified brightness range. For instance, let us determine the mean deviation for each reproduction of contrast for an object having a range of $B = 1$ to $B = 40$. The vertical line drawn through the point $\log B_o = 1.4$ now limits the areas which must be integrated in order to find the desired deviation. The values obtained for the three curves are given in column D (Table III). It is thus possible to determine the magnitude of the departure from exact reproducion of contrast of any desired range of object brightness values, when reproduced by means of negative and positive materials of known characteristics.

From a consideration of Fig. 10, a conclusion of considerable importance in practical work may be drawn. This relates to the problem of choosing the printing paper best adapted to a given negative or the inverse problem of making a negative of the proper quality for printing on a given printing paper. Considering Curve B, it will be seen that the useful portion is limited by the points m and n. On portions of the curve lying outside of these limits the gradient $\frac{d D'_p}{d \log E_y}$ is so small as to be practically useless in the reproduction of differences in E_y. Now in practice it is, in the great majority of cases, desirable to render the deepest shadow (lowest brightness) of the object by the maximum useful density of the positive material, and the highest light (greatest brightness) by the minimum useful density of the printing material, and at the same time to render all of the brightness differences of the object as density differences in the finished print. If the density in negative by which the highest light of the object is rendered be designated by the symbol $D_n max$, and that negative density which renders the deepest shadow be designated by $D_n min$, it is evident in order to fulfill the condition stated in the previous sentence that $D_n max. - D_n min. = ES_y$. The quantity $(D_n max. - D_n min.) = DS_n$ is termed the "density scale of the negative" and applies to a particular negative. This term (DS_n) should not be confused with the similar term DS_x which applies to the nega-

tive material itself with a meaning exactly parallel to that of DS_y as applied to the positive material.

From a consideration of Fig. 10, it will be seen if the negative and printing paper be such that $DS_n = ES_y$, that all of the density differences in the negative will be rendered as density differences in the print, and further, that the maximum negative density will be rendered as the minimum useful density of the printing material while the minimum negative density will result in the maximum useful density in the print. Such procedure, of course, results in the loss of contrast in the extreme shadows and highlights due to the shape of the characteristic curve of the printing paper, even though (as is usually possible) all of the object brightnesses are rendered on the straight line portion of the negative curve. Of two printing papers having identical values of ES_y (and equal to the value of DS_n for the negatives considered), the better result will in general be obtained by use of the one of which the characteristic curve most closely approximates to a straight line between the points m and n. While in some special cases better results may be obtained by some other procedure, it is undoubtedly true that in general the most favorable relation between negative and printing paper is that the "density scale" DS_n of the former shall be as nearly as possible equal to the "exposure scale" DS_y of the latter.

Since it is not the primary object of this paper to deal with particular cases, but rather to outline the general theory of the subject, the discussion of the objective phase will be closed at this point, leaving the application to practical problems for treatment in subsequent papers. Moreover, a final evaluation of the quality of a reproduction cannot be made without a consideration of the subjective phase of the problem, and this will now be treated.

THE SUBJECTIVE PHASE.

Turning now to a consideration of the subjective phase, it will be well to discuss the significance of the curves shown in Fig. 3. These contain the data relative to the visual sensitivities necessary for the evaluation of the subjective relative-contrast function. Curve A gives the relation of the sensation to the stimulating brightness. Equal increments on the Y axis correspond to equal increments in the sensation and the brightness intervals which give rise to these sensation steps can be determined from this curve. The shape of this function could be established by

direct experiments, but since such a process is extremely laborious, it is customary to arrive at the same end by other means. The curve B, the contrast sensibility, is the first derivative of the sensation curve, hence, if the sensibility be measured and the curve B plotted, the sensation curve may be obtained by integration. The sensibility at a given adaptation level is determined by measuring the least difference in brightness perceptible under the specified conditions. The least perceptible difference, ΔB, expressed as a fraction of the brightness at which it is determined, is a direct measure of the sensibility of the eye to contrast or brightness difference. The data from which the curve B is plotted are given in Table IV, and are from the work of Nutting and Blanchard (*loc. cit.*). The ordinate of curve B at any point is therefore equal to the slope of the curve A at the same value of B. Thus, if S be the sensation, $\frac{d\,S}{d\,\log\,B} = \frac{B}{\triangle B}$. The values of the ordinates of the sensation curve are in terms of sensation units, and the construction of such a sensation scale is based on the assumption that a just perceptible difference at any point on the sensation scale is equal to a just perceptible difference at any other point. The basic unit upon which this scale is established is therefore the least perceptible brightness difference.

It will be noted from the data in Table IV that the range of brightness over which the eye operates is enormous, from $B = .000001$ to $B = 10000$ millilamberts, a range of 1 to 10,000,000,000, while for the photographic plate the corresponding range is but 1 to 2000 (approximately). This extreme range in case of the eye is due largely to the fact that the retina changes in sensibility with the intensity of the incident radiation. This property of variable sensibility has been likened to that of an ammeter equipped with a shunt whose resistance decreases as the current increases. The diameter of the pupil is but a very small factor in the sensibility change since it varies in area over a range of but 1 to 64. It should be pointed out that the curves in Fig. 3 are similar in shape to those given by Renwick (*loc. cit.*) but that the absolute values of log brightness are very different. This is due undoubtedly to the uncertainty in the value of the unit used by König, from whose data the curves in question were plotted. Blanchard (*loc. cit.*) has discussed the question and has computed the probable value of König's unit as being .004 ml. (approxi-

mately). The millilambert is the c. g. s. unit of brightness, and is equivalent to a brightness of ten meter candles or .93 foot candles. The region of maximum sensibility is therefore from 3 to 250 foot candles (approximately), instead of from 20,000 to 400,000 as indicated by the curves published by Renwick. Since the function of use in relating subjective reproduction to the objective contrast is obtained by using the ratio of the gradients at two points on the sensation curve, the units in which the curve is plotted are not of importance. However, in order to determine the sensibility for a given adaptation level, it is important that the correct abscissæ value be used.

Now, if we consider a specified brightness difference in the object viewed with the eye adapted to some brightness level A_o, it is possible from curve A (Fig. 3) to find the corresponding sensation difference; and if the brightness difference between the corresponding areas of the material reproduction be known, together with the adaptation level (A_{mr}) of the observer viewing this material reproduction, it is possible to determine also the

TABLE IV.

Visual Sensitometric Data

Field Brightness	Difference Fraction	Discrimination Factor	Threshold Limit
0.000001	(1.00)	1.0	0.00000093
0.00001	(0.66)	1.5	0.0000042
0.0001	0.395	2.5	0.000019
0.001	0.204	4.5	0.000087
0.01	0.078	12.8	0.00039
0.1	0.0370	27.0	0.00174
1.0	0.0208	48.2	0.0081
10.0	0.0174	57.5	0.036
100.0	0.0172	58.1	0.28
1000.0	0.0240	41.7	2.15
10000.0	(0.048)	(20.9)	(232.0)

magnitude of the resulting subjective contrast. A comparison of the magnitudes of these two contrast values namely: (*a*) the subjective contrast resulting from observation of the object at a given adaptation level, which subjective evaluation it is convenient to refer to as the subjective object; and (*b*) the subjective contrast due to the observation of the material reproduction at a specified adaptation level, which subjective evaluation will be termed the

subjective reproduction; determines the exactness with which the subjective sensation resulting from the observation of the object is reproduced by observation of the material reproduction (the illuminated positive) under the conditions specified. It is also possible by similar methods to determine the magnitude of the contrast necessary, at any point in the tonal scale of the material reproduction, for the exact reproduction of the subjective contrast of the object, assuming, of course, that the values of A_o and A_{mr} are known

A_o = Adaptation level while observing object.
A_{mr} = Adaptation level while observing material reproduction.

For instance, in Fig. 12 consider an increment of brightness, $\Delta \log B_1 = \log B_1 - \log B_1'$, for which the corresponding increment in the sensation is $\Delta S_1 = (S_1 - S_1')$. At any other point take a second increment in sensation $\Delta S_2 = (S_2 - S_2')$ such that $\Delta S_1 = \Delta S_2$. Let the increment in $\log B$, corresponding to ΔS_2, be represented by $\Delta \log B_2 = (\log B_2 - \log B_2')$. Assume that the increment $\Delta \log B_2$ applies to some point in the object, and that the value of $\log B_2$ fixes the adaptation level of the observer looking at that object, while for the material reproduction the adaptation is conditioned by the value of B_1

$$A_o = B_2$$
$$A_{mr} = B_1$$

Now the average slope of the curve (Fig. 12) over the range $\Delta \log B_2$ is given by,

$$\text{Slope (2)} = \frac{\Delta S_2}{\Delta \log B_2}.$$

And the average slope over the interval $\Delta \log B_1$ is likewise,

$$\text{Slope (1)} = \frac{\Delta S_1}{\Delta \log B_1}.$$

Since $\Delta S_1 = \Delta S_2$ it follows that

$$\frac{\text{Slope (2)}}{\text{Slope (1)}} = \frac{\Delta \log B_1}{\Delta \log B_2}$$

But the average slope of the sensation curve over any given interval is given by the average value of the ordinate, D, of the contrast sensibility curve (Curve B, Fig. 3) over the same in-

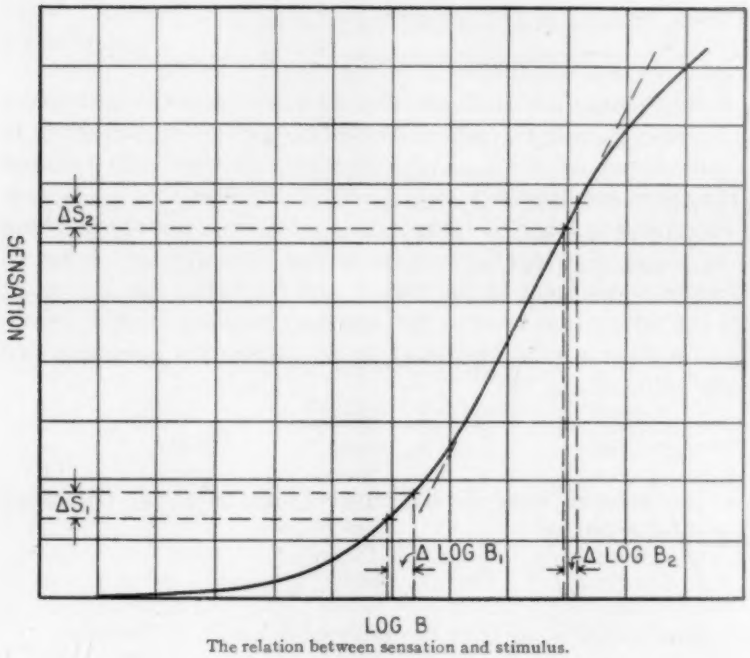
terval. Hence, we may express the values of the slope by the corresponding values of D, and equation becomes

$$\frac{\text{Average } D_2}{\text{Average } D_1} = \frac{\Delta \log B_1}{\Delta \log B_2}$$

or

$$\Delta \log B_2 = \Delta \log B_1 \cdot \frac{\text{Average } D_1}{\text{Average } D_2}$$

FIG. 12.



The relation between sensation and stimulus.

It is evident, therefore, if $\Delta \log B_2$ be the objective brightness difference at some point in the object that the equation will give the value of the $\Delta \log B_1$, the objective brightness difference necessary in the photographic reproduction for the exact reproduction of subjective contrast. In the case illustrated, the interval $\Delta \log B_2$ is less than the interval $\Delta \log B_1$, thus indicating that a greater objective contrast in the reproduction will be required to reproduce the subjective contrast due to the smaller objective contrast in the object.

It is well known that other factors than the brightness of the area upon which the attention is fixed (foveal image) influence to some extent the adaptation level of the eye at any instant. Such factors include the brightness of the surrounding objects (*i.e.*, the peripheral images), and the length of time during which the attention has been fixed on the area considered. In practice, however, the picture being observed occupies a very considerable portion of the field of vision, and, further, in the great majority of such pictures the actual range of brightness is relatively limited. This is especially true of surfaces viewed by reflected light. Further, under the majority of conditions, the field of vision not filled by the reproduction being considered does not contain any area contrasting extremely with the brightness of the reproduction. It seems reasonable, therefore, to assume that the adaptation level will be fixed in practice by the brightness of the reproduction itself, and likewise that the level when viewing the object will be conditioned by the object considered.

The question then arises as to what particular brightness in object and reproduction will determine the adaptation level in each case. Considering the reproduction as a reflecting surface, the average range of brightness may be taken as 1 to 40 (1.6 in log B_{mr}), which, even at the steepest part of the sensibility curve (Fig. 3) does not correspond to an excessive change in value of D. The change in adaptation as attention travels from highlight to shadow probably is not so great as that indicated by the brightness range, being limited to some extent by the stabilizing effect of the peripheral images as well as to the time lag of adaptation behind the changing foveal stimulus. It seems logical, therefore, to assume that A_o and A_{mr} are conditioned by the average brightness of object and material reproduction, and this assumption will undoubtedly hold for a large percentage of the normal cases, although it may be necessary, under extreme conditions, to take into account the change in adaptation (and consequently in the value of D) which occurs as attention shifts from an area of one brightness to that of another.

As a simplifying condition, let us, therefore, assume that the adaptation level is conditioned by a brightness of the object and reproduction respectively half-way between (on the log B scale) the highest and lowest brightness considered.

Let the values of the various factors be designated by:

For the object:

A_o = Adaptation Level for Average B_o.

D_o = Sensibility.

For the reproduction:

A_{mr} = Adaptation Level for Average B_{mr}.

D_{mr} = Sensibility.

Now in the equation previously given,

$$\frac{\text{Average } D_2}{\text{Average } D_1} = \frac{\Delta \log B_1}{\Delta \log B_2}$$

let the numerical subscripts be replaced by the subscript letters indicating the application of the terms to particular values, thus,

$$\frac{\text{Average } D_o}{\text{Average } D_{mr}} = \frac{\Delta \log B_{mr}}{\Delta \log B_o}$$

By allowing these finite increments to approach zero as a limit, we may replace the average values of D by values of the slope of the contrast sensibility curve at a point and obtain the expression

$$\frac{D_o}{D_{mr}} = \frac{d \log B_{mr}}{d \log B_o}$$

Since previously an assumption of equality of subjective contrast (sensation increment) was made, this equation is a statement of the conditions necessary for the exact reproduction of the subjective contrast.

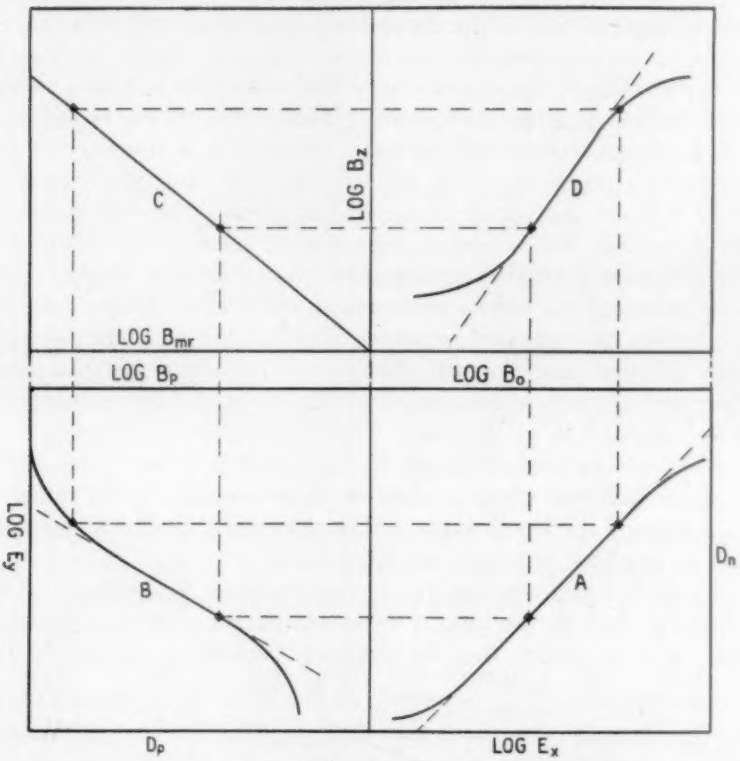
Now the value of $\frac{D_o}{D_{mr}}$ gives the slope of a curve which if plotted in Quadrant *I*, Fig. 4, would be the line of exact subjective reproduction of objective contrast. In the graphic solution, however, it is more convenient in plotting the reproduction curve D, and also in the later interpretation of the results, to retain the line E (of which the gradient is unity) as the line of exact contrast reproduction, and to alter the position of the points on the scale on the line O so that the reproduction curve plotted therefrom will be the curve of actual subjective reproduction, this alteration of position being an expansion or compression of the points on the scale in the case of constant values for the adaptation levels (A_o and A_{mr}), or a distortion of their distribution in case

such values are variable. It is quite possible to obtain the final evaluation of the exactness of reproduction as a comparison between the contrast values of the subjective object and the subjective reproduction (see Table I, Items I and X), but in view of the fact that the starting point in any tone reproduction problem must be the objective brightness values of the object, it seems more logical to make these values the primary base of the computation and to express finally the departures from exact reproduction in terms of these physically measured values of object brightness. This necessitates the evaluation of the subjective contrast of the reproduction in terms of the subjective contrast of the object, and a final expression of this complex relation as a function of the object brightness B_o. The final comparison must therefore be made between the actual measured (objective) contrast values of the object and the corresponding contrast values of the subjective reproduction evaluated in terms of the subjective object. The scale on which the points representing the various areas of the reproduction as evaluated in terms of this relative subjective contrast function, must occupy the line OY in order that the curve representing the final reproduction may be graphically constructed with values of B_o as abscissæ. The required scale constructed on line OY will be termed the log B_z scale, and the relative subjective contrast function which is used to determine the distribution of the points on the log B_z scale will be referred to as the Z function, and its gradient will be designated by G_z.

Now in order that the line E (in Quadrant I), having a slope of unity, shall be the line of exact subjective contrast reproduction, it is necessary that its slope or gradient be given by the expression $G_e = \frac{\triangle \log B_z}{\triangle \log B_o}$ where $\Delta \log B_o$ is some increment on the log B_o scale for which the corresponding interval in the subjective reproduction is $\Delta \log B_z$. Let the scale of log B_{mr} on line OY (Fig. 4) be replaced by a scale of log B_z (Fig. 13). This can be accomplished by replacing the dummy curve C (Fig. 4), by the new function which gives the relation between the material (objective) reproduction and the subjective reproduction. This subjective reproduction is itself a complex function containing the relation between the subjective evaluation on the object and subjective evaluation of the material reproduction. These evaluations are conditioned by the sensibility of the eye to brightness dif-

ferences (contrast) at the time of observing the object and when viewing the reproduction. This relation, the relative subjective contrast function, can be constructed graphically, but the consideration of this will be omitted. It is sufficient for the present purpose to state that the gradient of this curve, which must be

FIG. 13.



Special case of the complete solution including subjective phase.

substituted for the dummy curve thus far used, is equal to the reciprocal of the ratio of the values of D_o to D_{mr}. Let G_z indicate the gradient of the relative subjective contrast function which from this point on will be used instead of the dummy curve, having an arbitrary gradient equal to unity.

$$G_z = \frac{D_{mr}}{D_o}$$

This procedure also makes it possible to establish on the line OY the scale log B_z (Fig. 13), for which the points located by the usual construction methods will represent the relative subjective brightnesses corresponding to the various areas of the object considered.

Now if

$$D_o = D_{mr}$$
$$G_z = 1.0 = G_d$$

This is the gradient thus far used in the construction of the curve C. It is evident, therefore, if average B_o and average B_{mr} are such that they fall between the limits (Fig. 3), log $B = 0.5$ ($B = 3.2$ ml.) and log $B = 2.2$ ($B = 166$ ml.) that the subjective reproduction of contrast will be identical with the material reproduction curves already discussed.

If, however, the brightness, B_o, of the object and the consequent adaptation level, A_o, of the observer viewing that object is relatively high, while the brightness of the material reproduction, B_{mr} (the illuminated positive), and the corresponding adaptation level, A_{mr}, is low, the subjective reproduction will be different from the objective reproduction. In this case the contrast sensitility D_o is greater than D_{mr} and hence the gradient, G_z, of the relative subjective contrast curve is less than unity.

$$G_z = \frac{D_{mr}}{D_o}$$

The reproduction curve, D, constructed in the usual way will also have a decreased gradient. This indicates that under such conditions a loss of contrast occurs due to the subjective factors, and in order to obtain exact subjective reproduction it will be necessary to enhance the objective contrast in material reproduction, in order to compensate for the loss due to the subjective effect. It is evident from these considerations that a picture of a brilliantly light scene, which is to be viewed under relatively low illuminations, such as exist in interiors at night should be somewhat more contrasty than the scene itself. That is, best subjective reproduction will be obtained by a positive in which the actual objective contrast is somewhat enhanced. This condition may be stated symbolically thus:

If,

D_o is greater than D_{mr},
G_z is less than 1.0.

When G_z is less than unity there will be a loss of contrast due to the subjective factors.

On the other hand if,

D_o is less than D_{mr},
G_z is greater than 1.0,

and there will be an enhancement of contrast due to the subjective factors. When G_z is greater than unity the slope of the relative subjective contrast function (Curve C is Quadrant IV) is greater than unity, and the gradient of the resulting reproduction curve D (Quadrant I) is increased accordingly.

Now from a consideration of Fig. 13 it will be seen that:

$$G_n = \frac{d\,D_n}{d\,\log E_x} = \frac{d\,D_n}{d\,\log B_o}$$

$$G_p = \frac{d\,D'd}{d\,\log E_y} = -\frac{d\,D'd}{d\,D_n} = \frac{d\,\log B_{mr}}{d\,D_n}$$

$$G_p \cdot G_n = \frac{d\,\log B_{mr}}{d\,\log B_o}$$

$$G_z \text{ (Curve } C) = \frac{d\,\log B_z}{d\,\log B_{mr}} = \frac{D_{mr}}{D_o}$$

$$G_r \text{ (Curve } D) = \frac{d\,\log B_z}{d\,\log B_o}$$

$$G_n \cdot G_p \cdot G_z = \frac{d\,\log B_{mr}}{d\,\log B_o} \cdot \frac{d\,\log B_z}{d\,\log B_{mr}}$$

$$= \frac{d\,\log B_z}{d\,\log B_o} = G_n$$

$$\therefore G_n \cdot G_p \cdot G_z = G_r$$

For the straight line portions of the curves, if such exist,

$$\gamma_n\ \gamma_p \cdot \gamma_z = \gamma_r$$

Therefore if any three of these four functions involved be known or are assumed, the fourth may be determined. The line E as before is the curve of exact reproduction of contrast, and the curve D is the reproduction obtained under the specified conditions. Deviations may be determined as in case of the solution for the objective phase, and the results will indicate the departure

from the exact reproduction of subjective contrast. It should be noted that this construction gives direct comparison between the objective values of brightness and the relative subjective equivalent in the reproduction. That is, the comparison is not between the subjective impression of the object and the subjective impression due to the reproduction, although this comparison can easily be made if such seems desirable. The procedure adopted is such that all of the subjective factors are introduced by use of the curve C, the relative subjective contrast function, such procedure in effect is the evaluation of the subjective reproduction in terms of the subjective contrast in the object itself.

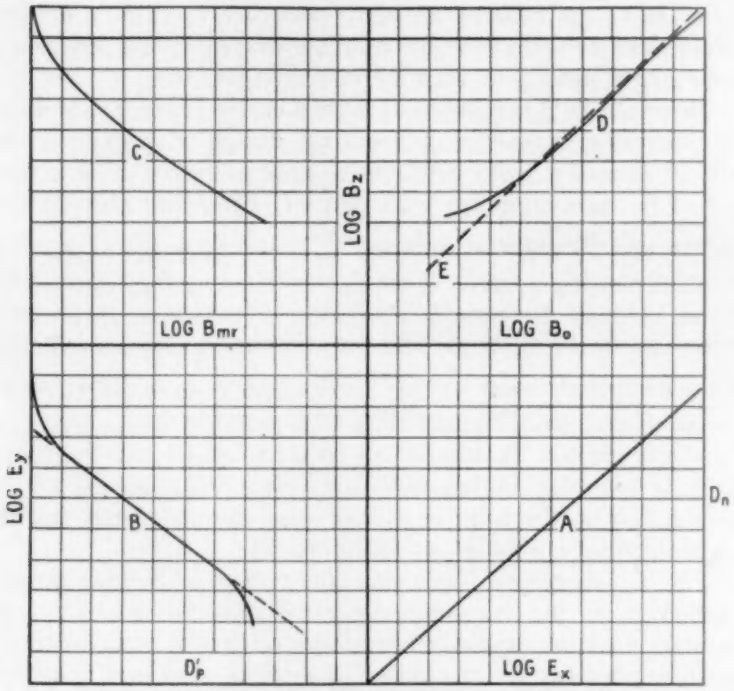
Now in case it is considered necessary, by reason of the existing conditions, to take into account the change of adaptation with shift of attention from highlight to shadow, this can be accomplished by computing for each pair of object and reproduction brightnesses the value of the ratio $\frac{D_{mr}}{D_o}$, and from the values thus obtained plotting a curve which is then used as the relative subjective contrast function. The curve C may not, under such circumstances, be a straight line, but will vary in slope as indicated by the computed values of $\frac{D_{mr}}{D_o}$. As a typical example of such a case computed from actual values of a practical case, curve C in Fig. 14 is given. This is for an object in which the brightness range is from 15 ml. to 1000 ml., while the intensity of the illumination on the positive during observation is such that the brightness range is from .35 ml. to 10 ml.

Fig. 14, therefore, represents the complete general graphic solution giving the reproduction curve D, which is a graphic representation of the reproduction of the subjective impression obtainable under any set of specified conditions, the line E being the curve of exact reproduction of subjective contrast. It should be noted that with the particular values assumed in this case, the reproduction curve D is somewhat straighter in the highlight region than when a straight line was used as the relative subjective contrast function. It is probable in practice that the change in adaptation level is not so great as is indicated by the assumptions made in this case, and that the improvement in contrast reproduction is not so great as indicated by the curve shown.

Many interesting relations between the various factors may be derived and applied to practical problems, but the discussion of

such details will not be taken up at this time. One point deserving mention at this time, however, is relative to the values of adaptation of the eye, upon which depend the sensibility values from which the slope of the subjective relative-contrast function is computed. Few data are at present available as to adaptation levels when the visual field is filled by areas of different bright-

FIG. 14.



A general case of the complete solution including the subjective phase.

nesses, such as exists under practical conditions. Experimental work is at present in progress in this laboratory, from the results of which it is hoped more reliable evaluations of A_o and A_{mr} may be obtained for certain specified practical conditions. When these data are available, it will be possible by the application of the general principles outlined in this paper to arrive at more certain conclusion, relative to the exactness of reproduction in any particular case.

PRESENTATION OF THE FRANKLIN MEDAL.
MAY 19, 1920.

AT the Stated Meeting of the Committee on Science and the Arts held March 3, 1920, the following resolutions were adopted:

"*Resolved* That The Franklin Medal be awarded to Sir Charles Algernon Parsons, of England, in recognition of his epoch-making success in the development and construction of the steam turbine, which has revolutionized the art of steam engineering, particularly in regard to the propulsion of mercantile and naval vessels, and the driving of electrical generators."

"*Resolved*, That The Franklin Medal be awarded to Professor Svante August Arrhenius, of Sweden, in recognition of his notable contributions to the theory of physical science, which have found unprecedentedly extended and fruitful application in the experimental study of chemical, physical, biological and cosmic phenomena, as well as in industrial chemistry."

CORRESPONDENCE WITH MEDALISTS.

THE FRANKLIN INSTITUTE
OF THE STATE OF PENNSYLVANIA
Philadelphia

OFFICE OF THE SECRETARY — MARCH 26, 1920.

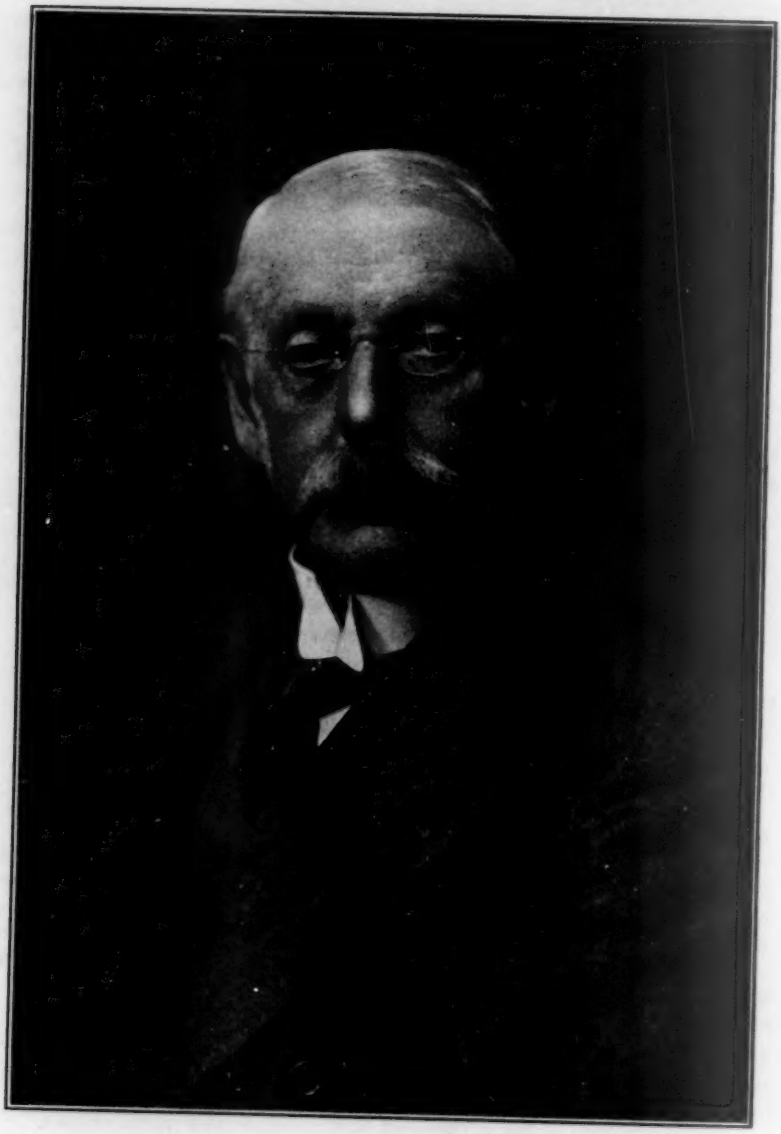
Sir Charles Algernon Parsons, K.C.B., C.B., M.A., LL.D., D.Sc., F.R.S.,
6, Windsor Terrace,
Newcastle-on-Tyne,
England.

SIR:

I have the honour to inform you that The Franklin Institute has awarded you The Franklin Medal, founded for the recognition of those workers in physical science or technology, without regard to country, whose efforts in the opinion of the Institute have done most to advance a knowledge of physical science or its applications. The award is minuted as follows:

> "That The Franklin Medal be awarded to Sir Charles Algernon Parsons, of England, in recognition of his epoch-making success in the development and construction of the steam turbine, which has revolutionized the art of steam engineering, particularly in regard to the propulsion of mercantile and naval vessels, and the driving of electrical generators."

The medal and accompanying certificate are being prepared, and Sir Auckland Geddes, your Government's Ambassador at Washington, is



Charles A. Coffin.

being requested to come to the Institute on the afternoon of Wednesday, May 19th, to receive this medal and certificate on behalf of his Government, for you. I am,

Respectfully,

(Signed) R. B. OWENS,
Secretary.

RBO: S

THE FRANKLIN INSTITUTE
OF THE STATE OF PENNSYLVANIA
Philadelphia

OFFICE OF THE SECRETARY MARCH 26, 1920.

Professor Svante August Arrhenius, Ph.D., M.D., D.Sc., LL.D.,
Director, Physico-Chemical Department,
Nobel Institute,
Stockholm, Sweden.

SIR:

I have the honour to inform you that The Franklin Institute has awarded you The Franklin Medal, founded for the recognition of those workers in physical science or technology, without regard to country, whose efforts in the opinion of the Institute have done most to advance a knowledge of physical science or its applications. The award is minuted as follows:

"That The Franklin Medal be awarded to Professor Svante August Arrhenius, of Sweden, in recognition of his notable contributions to the theory of physical science, which have found unprecedentedly extended and fruitful application in the experimental study of chemical, physical, biological and cosmic phenomena, as well as in industrial chemistry."

The medal and accompanying certificate are being prepared, and Mr. W. A. F. Ekengren, your Government's Minister at Washington, has been requested to come to the Institute on the afternoon of Wednesday, May 19th, to receive this medal and certificate on behalf of his Government, for you. I am,

Respectfully,

(Signed) R. B. OWENS,
Secretary.

RBO: C

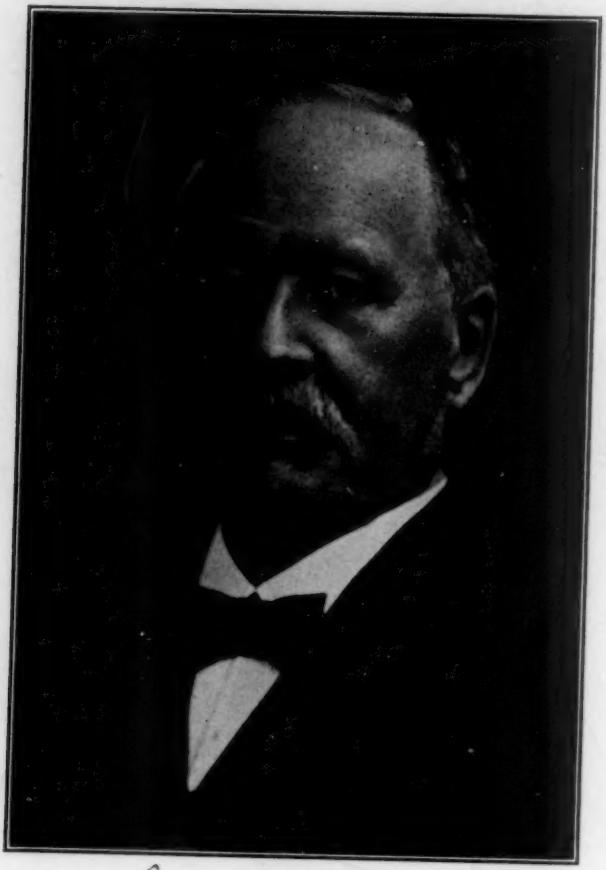
THE FRANKLIN INSTITUTE
OF THE STATE OF PENNSYLVANIA
Philadelphia

OFFICE OF THE SECRETARY APRIL 1, 1920.

Sir Auckland Geddes, Ambassador Extraordinary,
and Plenipotentiary of His Britannic Majesty,
British Embassy,
Washington, D. C.

YOUR EXCELLENCY:

I have the honour to inform you that The Franklin Institute has awarded to Sir Charles Algernon Parsons, of Newcastle-on-Tyne, Eng-



Svante Arrhenius
Sept. 1918.

land, The Franklin Medal, founded for the "recognition of those workers in physical science or technology, without regard to country, whose efforts in the opinion of the Institute have done most to advance a knowledge of physical science or its applications." The award is minuted as follows:

> "That The Franklin Medal be awarded to Sir Charles Algernon Parsons, of England, in recognition of his epoch-making success in the development and construction of the steam turbine, which has revolutionized the art of steam engineering, particularly in regard to the propulsion of mercantile and naval vessels, and the driving of electrical generators."

The medal and accompanying certificate are being prepared, and I am requested, on behalf of our management, to extend to you a cordial invitation to come to the Institute on the afternoon of Wednesday, May 19th, to receive this medal and certificate from our President, on behalf of your Government, for Sir Charles.

A second medal has been awarded to Professor Svante August Arrhenius, of the Nobel Institute, Sweden, in recognition of his notable contributions to physical science.

You and Mr. W. A. F. Ekengren, Swedish Minister at Washington, will be asked to be guests of honour at a dinner to be given on the same evening, but in this connection our President, Dr. Walton Clark, will communicate further with you.

I am,

Your Excellency's very humble servant,

(Signed) R. B. OWENS,
Secretary.

RBO:C

THE FRANKLIN INSTITUTE
OF THE STATE OF PENNSYLVANIA
Philadelphia

OFFICE OF THE SECRETARY — APRIL 1, 1920.

W. A. F. Ekengren, Esq.,
Envoy Extraordinary and Minister Plenipotentiary,
of His Swedish Majesty,
Swedish Legation,
Washington, D. C.

SIR:

I have the honour to inform you that The Franklin Institute has awarded to Professor Svante August Arrhenius, of the Nobel Institute, Stockholm, The Franklin Medal, founded for the "recognition of those workers in physical science or technology, without regard to country, whose efforts in the opinion of the Institute have done most to advance a knowledge of physical science or its applications." The award is minuted as follows:

> "That The Franklin Medal be awarded to Professor Svante August Arrhenius, in recognition of his notable contributions to the theory of physical science, which have found unprecedentedly

extended and fruitful application in the experimental study of chemical, physical, biological and cosmic phenomena, as well as in industrial chemistry."

The medal and accompanying certificate are being prepared, and I am requested, on behalf of our management, to extend to you a cordial invitation to come to the Institute on the afternoon of Wednesday, May 19th, to receive this medal and certificate from our President, on behalf of your Government, for Professor Arrhenius.

A second medal has been awarded to Sir Charles Algernon Parsons, of Newcastle-on-Tyne, England, in recognition of his epoch-making success in the development and construction of the steam turbine.

You and Sir Auckland Geddes, British Ambassador at Washington, will be asked to be guests of honour at a dinner to be given on the same evening, but in this connection our President, Dr. Walton Clark, will communicate further with you.

I am,

Respectfully,

(Signed) R. B. OWENS,
Secretary.

RBO:S

LEGATION OF SWEDEN
Washington, D. C.

APRIL 6, 1920.

Mr. R. B. Owens, Sec'y.,
Franklin Institute,
Philadelphia, Penna.

SIR:

I have the honor to acknowledge, with best thanks, the receipt of your kind letter of the 1st inst., inviting me to come to The Franklin Institute in the afternoon of Wednesday, May 19th, to receive on behalf of my Government the Franklin Medal which has been awarded to Professor Svante August Arrhenius of Stockholm.

In reply, I would state that I shall come with much pleasure.

Cordially yours,

(Signed) EKENGREN,
Minister of Sweden.

LH:GH

NOBEL INSTITUTE
EXPERIMENTALFALTET
Sweden

APRIL 19, 1920.

DEAR DOCTOR OWENS:

It was an extraordinarily great honor and pleasure to receive your two letters of March 26th which I received on April 14th. The mail is very slow nowadays. If it takes the same time back, you will, I hope, have this answer after 18 days, *i.e.*, on May 6th, in due time before the meeting on May 19th.

In order that you should have this letter as soon as possible and surely before the 19th of May, I have had to write my biographical sketch (with my last photo) and a small paper rather rapidly. I, therefore, suppose that some errors or unusual phrases have crept into the writings. I would, therefore, be extremely glad, if you would kindly let some one in America look through them for making the necessary corrections.

I hope also that the printer will be able to read the manuscript, although it is not typewritten, but I think it will be necessary to read the proofs rather carefully.

I would be glad to receive some copies, *e.g.*, 25, of this small paper.

The content of it has interested me for a very long time, as is easily seen from my book "Worlds in the Making," Chap. 2. I think that it will be necessary to make an international law against the wasting of natural treasures, which are not constantly reproduced by Nature, through solar radiation. It will also be necessary to ration coal and also some ores in order that countries which do not possess deposits of these necessities, shall not become poor and starve. For coal is now as necessary as bread and we in Europe suffer very much from the bad situation, regarding coal and also iron ores, which is due to the dictates in the peace treaty and which prevents the economical restoration of Europe.

I think that these questions are the most important for humanity and that it is of the greatest consequence that they draw the attention of industrials and statesmen.

I would be very thankful if you were so kind as to say my most respectful thanks to the members of The Franklin Institute for the highly appreciated honor which they have bestowed upon me.

Believe me to be,

Yours faithfully,

(Signed) SVANTE ARRHENIUS.

BRITISH EMBASSY
Washington

APRIL 24, 1920.

DEAR MR. OWENS:

It will give me great pleasure to come to Philadelphia on May 19th to receive on behalf of my Government the Franklin Medal awarded by your Institute to Sir Charles Algernon Parsons. It is particularly gratifying to myself, as a student of science, that my first visit to your city should take place under circumstances which emphasize the friendly coöperation of the two great English-speaking races in the advancement of scientific knowledge.

Very truly yours,

(Signed) A. GEDDES.

R. B. Owens, Esq.,
Secretary, The Franklin Institute,
Philadelphia,
Pennsylvania.

1, UPPER BROOK ST.,
W. I.,
27 APRIL.

DEAR PROFESSOR OWENS:

I have been anxiously considering how to meet your kind wishes in regard to a paper for your May Meeting in the allotted time, and besides I have not been very well or energetic.

As you say, the subject "Notable War Inventions" has been more or less covered in my B. A. address and "The Steam Engine and Industrial Progress" in another of my publications.

A paper dealing with "The Steam Turbine of Today" would take some time to prepare.

I, therefore, came to the conclusion that though perhaps unusual, just a few reminiscences of the early days of turbine development, which would occupy but a few minutes, might be appropriate and to some extent new.

I have pleasure in sending you the only good report of my lecture this spring at the Royal Institute on "High Temperatures and Pressure," also copy of my paper on "Diamond Researches" and copies of my B. A. address.

I must again express my deep appreciation of the honor of The Franklin Medal.

I am looking forward when things have settled down here of paying another visit to America. I well remember with the greatest pleasure my visit to Philadelphia in 1884.

With very kind regards,
I am,
Yours very sincerely,
(Signed) CHARLES A. PARSONS.

TELEGRAM FROM HIS EXCELLENCY, MR. EKENGREN, TO DR. R. B. OWENS, SECRETARY, DATED MAY 17, 1920.

Have been quite seriously ill for some time, but however have right along had every reason to believe that I should be well enough to come to Philadelphia, Wednesday, to receive, on behalf of the Swedish Government, the medal with which your Institute has honored my illustrious countryman, Dr. Arrhenius. I was discharged from the hospital about a week ago, and in my opinion have been progressing normally, but to my consternation my physician tells me today that he will under no circumstances permit me to take the trip. If I had only myself to consider I should, I assure you, be greatly inclined to disobey my Doctor's orders and come to Philadelphia, as I have promised, but as it is I must consider the position here that my Government has entrusted me with, as I must also consider my family.

Under the circumstances I must therefore refrain from disregarding my Doctor's orders.

Mr. Joen De Lagerberg, who is the Legation's Secretary, will consequently represent me. He will be accompanied by our Vice Consul in Philadelphia, Mr. Eric Brolin. Mr. Lagerberg will arrive in Philadelphia tomorrow afternoon, and will attempt to communicate with you then.

I assure you my unfortunate disability distresses me more than I can convey to you.

EKENGREN,
Swedish Minister.

PROGRAMME OF MEETING, MAY 19, 1920.

Presentation of The Franklin Medal to His Excellency, Sir Auckland Geddes, British Ambassador, on behalf of His Britannic Majesty's Government, for the Honourable Sir Charles A. Parsons, Newcastle-on-Tyne, England.

Presentation of The Franklin Medal to His Excellency, Mr. W. A. F. Ekengren, Minister of Sweden, on behalf of His Swedish Majesty's Government, for Professor Svante August Arrhenius, Nobel Institute, Stockholm, Sweden.

Papers:

"Some Reminiscences of Early Days of Turbine Development." Sir Charles A. Parsons, K.C.B., C.B., M.A., LL.D., D.Sc., F.R.S. Read by Mr. Charles Day, Vice-President, The Franklin Institute, Philadelphia.

"The Problem of the World's Supply of Energy." Professor Svante August Arrhenius, Ph.D., M.D., D.Sc., LL.D. Read by Allerton S. Cushman, Ph.D., Director, The Institute of Industrial Research, Washington, D. C.

PRESENTATION OF THE FRANKLIN MEDAL TO SIR CHARLES A. PARSONS AND PROFESSOR SVANTE AUGUST ARRHENIUS.

IN calling the meeting to order the President of the Institute announced that the business of the meeting would be the annual presentation of the Institute's highest award, The Franklin Medal, in recognition of distinguished scientific and technical achievement, and recognized Dr. Harry F. Keller, who made the following statement relative to the work of Sir Charles A. Parsons:

Mr. President: For the first time since The Franklin Medal was founded in 1914, both impressions of it are awarded to foreign scientists. On a previous occasion, in 1915, the two medals went to Americans, but as a rule one of the medalists was a foreigner and the other a compatriot of ours. In every instance, however, the Committee on Science and the Arts, in its recommendations for this award, has endeavored scrupulously to carry out the

provisions in the deed of gift that the recipients " without regard to country " be those " whose efforts, in the opinion of the Institute, have done most to advance physical science or its applications." On the present occasion our medalists could hardly be expected personally to receive from you this highest award in the gift of the Institute; but we are honored by the presence in our midst of official representatives of their Governments in this country who have graciously consented to accept, on behalf of their Governments, The Franklin Medals for their fellow-countrymen.

The first of these medals is awarded to the Honorable Sir Charles Algernon Parsons, K.C.B., of Newcastle-upon-Tyne, England. It is given to him as a tribute to his inventive genius, and in recognition, particularly, of his marvellous work on the steam turbine.

Sir Charles was born June 13, 1854, as the fourth son of the third Earl of Rosse, who was a President of the Royal Society, and built that famous telescope which is still the largest instrument of its kind.

The son received his early education entirely by private tuition, and later attended Dublin University and Cambridge, taking high honors as Eleventh Wrangler in the latter place. At that time (about 1877) he made models of his epicycloidal engine, and while serving a four years' apprenticeship in the Elswick Works he constructed the first engine of this type. It was a four-cylinder revolving engine in which the cylinders rotated around the revolving crank shaft. A large number of these engines were manufactured during the following two years.

Mr. Parsons then turned his attention to the development of the steam turbine. He conceived the idea of splitting up the fall in pressure over a great number of turbines in series, in order that the aggregate of these simple turbines, constituting a complete machine, would give an efficiency approximating that of water turbines. The great mechanical difficulties of producing such a machine were overcome by his indefatigable efforts.

In 1884 Mr. Parsons patented his first steam turbine. The first one he built was of 10 H.P., with 18,000 R.P.M., and was used for driving a high-speed dynamo. It marked the beginning of turbo-generator development for electric drive.

During the next five years he constructed many improved

forms of turbo-dynamos, and some 300 of these ranging in capacity up to 75 Kilowatts were turned out by the firm of which he was the junior partner. In 1889 he organized the works at Heaton, Newcastle-on-Tyne, and abandoning the parallel-flow system, began to experiment with turbines of the radial-flow type. In the paper prepared by Sir Charles, and to be read by Mr Day, the story of how there was tested every previous turbine invention, and many others since claimed as new, will doubtless be told us.

The first compound turbine was built in 1887, and the first condensing turbine in 1892, when there was at once a great advance in efficiency, the steam consumption being reduced from 55 lbs. to 27 lbs. per Kilowatt hour.

In 1895 the steam turbine was first applied to marine work, and two years later the experimental steamer *Turbinia,* driven entirely by turbines, was completed. She had a length of 100 feet, 9-foot beam, and 44 tons' displacement. The speed attained on her trial trip was 34 knots. During the following years larger vessels for which Parsons' Works at Wallsend supplied the turbines were built, each showing marked improvements over the preceding ones. In 1905 the *Amethyst,* equipped with turbines, beat her sister ship, the *Topaz,* which was driven by reciprocating engines. From this time on the construction of turbine-driven vessels advanced by leaps and bounds, until the present time, when the turbine has not only completely supplanted the reciprocating engine in war vessels, but to a great extent also, either wholly or partly, in the great ocean liners and mercantile steamers. It is to the constructive genius of Sir Charles Parsons that we owe the combination of reciprocating engines and steam turbines in many instances. By connecting the turbines to the propeller by gearing he has made possible another great stride in turbine propulsion.

The pioneer work of Sir Charles Parsons has brought about a revolution in the steam-driven machinery on land, as it has in that of ships. The central power plant of the present day would indeed be impossible without the steam turbine. It has been the means of producing steam-driven units up to 70,000 K.W., which are operated with only a fraction over ten pounds of steam per K.W. hour. While it is true that the development of the modern steam turbine is not to be credited to Parsons only, and that other great engineers have contributed their share to

it, it was he who first recognized the possibilities of the steam turbine, and the first to construct a practical machine. Nor should it be forgotten that since he first entered the field more than thirty years ago, he has been continuously active in the development and production of the new type of prime mover.

Sir Charles Parsons has made valuable contributions and inventions along other lines in physical science. Among them may be mentioned improvements in gramophones and investigations on the formation of diamonds. He must also be credited for the very active interest he has taken in technical education.

He is a Fellow of the Royal Society and has served as a member of its Council. His achievements have been recognized by honors and distinctions of all kinds, including honorary membership and medals from the leading engineering societies of various countries, degrees from great universities, the Freedom of the City of Newcastle-on-Tyne, and the Order of K.C.B., conferred upon him by His Majesty the King, in 1911.

The Franklin Medal awarded to him by The Franklin Institute, Mr. President, will now be accepted on behalf of His Majesty's Government, for Sir Charles, by His Excellency, Sir Auckland Geddes, the British Ambassador, whom I have the honor to present to you.

The President, in presenting The Franklin Medal to Sir Auckland Geddes, said:

Your Excellency, the members of The Franklin Institute are appreciative of the distinction conferred upon their meeting by the presence of a representative of the Government of Great Britain, and the Board of Managers of The Franklin Institute have commissioned and instructed me to convey to you the assurances of their high personal regard and their gratitude that you have come to take a part in our simple ceremony.

Your Excellency, I have the honor, in the name of The Franklin Institute, upon the recommendation of its Committee on Science and the Arts, to present to you, for transmission through the State Department of your Gracious Sovereign, to Sir Charles A. Parsons, the Franklin Medal and Diploma and a Certificate of Honorary Membership in The Franklin Institute.

The award to Sir Charles of this medal and these documents is in recognition of his distinguished services to mankind ren-

dered in the field of science. It is the highest honor in the gift of The Franklin Institute.

Sir Auckland Geddes in accepting The Franklin Medal on behalf of his Government for Sir Charles A. Parsons, said:

Mr. Chairman and Gentlemen: I regard it as a great honor to be privileged to receive at your hands the Medal which you have awarded to my distinguished fellow-countryman, the Honorable Sir Charles Algernon Parsons, K.C.B.

By your award of this medal you have shown clearly that you need no urging by me to appreciate what Sir Charles's invention of the steam turbine has meant and means to the naval architect, to the naval forces and mercantile marine of all nations as well as to those who are interested in supplying or receiving electric power as cheaply and economically as possible. By the same action you have shown something more with equal clarity. You have shown that your outlook is not limited by national frontiers, but that you can see across them in every direction and are willing, nay anxious, to recognize merit in the work of citizens of other lands.

Quite apart from the honor you have done Sir Charles Parsons, and in addition to it is the effect that such gracious acts of international courtesy have in sweetening international relations. I am no believer in what is called internationalism, but I do recognize that the many merits of national feeling are always liable to have some subtraction made from them on the ground that national patriotic enthusiasm is apt to be associated with an attitude of hostility towards, or perhaps more frequently, of contempt for other nations. I remember that as a boy I was firmly convinced that one Scot, I am a Scot, could be relied upon to deal with two Englishmen. I will not tell you how many men of other nations, according to my childish imaginings, it took to equal an Englishman, but I may say that a round dozen was not the limit.

These were extremely immature beliefs, but the common people of all lands cherish such beliefs to the end of their days, and when it came to war in 1914 it was no bad thing that the men of our contemptible little army were quite confident that they could take on four, five or more times their own strength in Germans and beat them.

In these days we have all had our fill of war, and we hope for peace in our time and in our children's time and in the time of our children's children. If we are to work to turn our hope into a reality, it is beyond question essential that we should continuously seek to see the good in nations other than our own, so that we approach all questions arising between ourselves and them not in a spirit of perhaps unconscious hostility or in a contemptuous frame of mind, but realizing that they, like ourselves, are contributors to the common stock of knowledge upon which, ethically and materially, the civilization of our day is founded.

It is, I think, no exaggeration to say that never has it been so necessary as it is to-day to seek to dispel the cloud of misrepresentation and misunderstanding which tends to separate the peoples of your country and of that which I have the honor to represent.

There are no misunderstandings that I know of, no lack of complete cordiality between the Governments of our two countries, yet many of your newspapers are filled with strange verbal pictures of what the British are, or are doing, which make me rub my eyes and wonder how, when, where such surprising stuff can be written. There are newspapers in England, only a few, thank God, that are filled with equally weird descriptions of your nation, its motives and its plans.

I am not speaking of criticism of action taken or not taken. There may be room for all sorts of criticism. That is a different story. I am speaking of wholly incorrect reports of simple facts and happenings.

To-day at this ceremony we have passed out of the Governmental into the popular sphere, and you have shown that you have no misunderstanding of the work and engineering triumphs of one of my distinguished fellow-countrymen. Behind all difficulties that ever have arisen between our nations, believe me there has always been one thing upon which you could count—there has been a rather formless but warm sentiment of desire for friendship associated with the word America in the average British mind. It will be all evil if that feeling is changed into one of less cordiality. Its existence is an asset to you and to us which you do well to foster. There can be no doubt that such ceremonies as this strengthen that sentiment and help it to acquire

some greater precision of form. Therefore, I am not only proud and glad to come here this afternoon to accept this beautiful medal which you have awarded to Sir Charles Parsons, but also grateful that I have had the opportunity personally to thank you for what this gracious act of yours means to that cause which we, who care for the continuance of the civilization we have known, all must have so deeply at heart—the cause of removing mutual misunderstandings and mistrusts from the minds of the peoples of Britain and America.

Doctor Keller was again recognized and presented the following statement of the work of Professor Svante August Arrhenius:

Mr. President: In rising to discharge the pleasant duty of presenting to you the distinguished representative of the Swedish Government, who will receive from you the second Franklin Medal, for Professor Svante August Arrhenius, I must confess to feeling no little embarrassment as to how I might give an appropriate summary of the life work of this great physicist in the brief space of time allotted to me. It seems an almost hopeless task upon which to venture.

The name of Svante Arrhenius is commonly associated with one of the greatest and most fruitful generalizations in the entire domain of chemistry—The Theory of Electrolytic Dissociation; but it is by no means this wonderful achievement alone that the Institute desires to recognize by the bestowal of its highest award upon the Swedish scientist, but rather the vast sum of constructive endeavor by which he has extended and illumined our knowledge of the physical universe.

Svante August Arrhenius was born at Castle Wijk, near Upsala, Sweden, February 19, 1859. His father was the manager of the Wijk estate and also of the adjoining university properties. His ancestors were farmers in Småland, Southern Sweden, where both of Svante's parents were born. It was from the name of the old Småland homestead, Årena, meaning river bank, that the latinized family name, Arrhenius, was derived.

Shortly after Svante's birth the father removed to Upsala to assume entire charge of the university's extended estates, and it was in this ancient town that the boy received his early education. In 1876 he was graduated from The Cathedral School, the youngest member of his class and near the head of it. His

work in mathematics and the sciences was particularly brilliant. After entering the university he made such rapid strides in his studies that he succeeded in passing the examinations for the degree of "candidate" at the end of the third semester. As his major subject he chose chemistry under Cleve's direction, but at the same time he zealously pursued mathematical studies, and in 1881 he decided to become a physicist. Not satisfied with the limited facilities of the Upsala laboratory, he went to Stockholm, where he worked under Edlund's direction, acquiring in rapid succession the degrees of "Licentiate" and of Doctor of Physics. His first original investigation was on the subject of voltaic polarization, and this was followed by "Researches on the Conductivity of Electrolytes," which he presented as his dissertation for the Doctorate, and which has since become a classic in the annals of exact science. In the same year, 1884, he published as a continuation to this paper the "Chemical Theory of Electrolytes." The two publications, though not entirely free from doubtful or debatable opinions, are most remarkable for the wealth of novel and fundamentally important ideas advanced in them. Particularly striking at that time was the suggestion that the affinity co-efficients of acids and bases should be proportional to their electrical conductivities, a prediction which it was impossible then to support by experimental data. But this Law of Arrhenius was shortly afterwards verified by Ostwald at Riga. In Sweden the results and views of Arrhenius were received with scepticism, bordering on contempt, but fortunately their true value was promptly recognized by leading scientists in other countries and particularly by Ostwald. This helped to overcome the prejudices of the Swedish chemists and physicists, and presently Arrhenius was permitted to "habilitate" himself as Dozent at Upsala, and a little later he was granted an ample stipend by the Swedish Academy, enabling him to make an extended tour to the leading seats of physical research in various countries. While at Leipzig, in 1887, he conceived the Theory of Electrolytic Dissociation, his *magnum opus,* in which the main ideas of his former publications are crystallized into one comprehensive and definite generalization. The way for a favorable reception of this achievement had in the meantime been prepared by the researches of Kohlrausch on the phenomena of electrolytic conduction, those of van't Hoff on osmotic pressure, and by Raoult's work on the

depression of the freezing point of liquids by a substance dissolved in them. All these, and others might be named that contributed materials for Arrhenius' theory.

The fertility of this Ionic Theory, as it came to be called, can hardly be overestimated; it is indeed without a parallel in physical science. For more than a decade after its announcement it prompted and directed innumerable researches, in the course of which many well-known, but hitherto unexplained phenomena were quantitatively elucidated. Among the subjects thus investigated may be mentioned the application of the theory to the law of mass action and its effect on the equilibria of the ions, culminating in the discovery of the law of dilution; a masterly study of the problem of chemical equilibrium of electrolytes; and also applications of the theory to such questions as the action of the voltaic pile, the analytical chemical reactions, the solubility of gases and many others.

It should be stated here also that soon after its publication Arrhenius' theory was successfully applied in the study and development of industrial, chemical and metallurgical processes. To it may be traced in a large measure the rapid progress that has been made during the past 25 years in many branches of applied chemistry, including some of the basic industries.

The signal success of Arrhenius as a pioneer in Physical Chemistry was recognized in his native country, as it had been abroad, and thus reacted favorably on his further career. In 1895 he received a call to the Chair of Physics in the then newly founded University of Stockholm. In this position he displayed such extraordinary ability as a leader and organizer, that the Faculty elected him Rector of the University in 1897. He was repeatedly re-elected to this responsible post, but later declined re-election, as he felt that the duties of the office seriously interfered with his scientific pursuits.

In 1903 he was awarded the Nobel Prize in physics, and two years later he was appointed Director of the Physical Institute of the Nobel Foundation. The laboratory building was erected according to his plans and under his direction.

Most of the papers on the Dissociation Theory were published by Arrhenius while he was working in foreign laboratories. After his return to Sweden his research work took different directions, largely along lines of cosmic physics. In

1905 he published a Treatise on Cosmic Physics in two volumes. In this remarkable work he embodied a series of investigations of which many were made by him and Ekholm jointly, while others were carried out by himself alone. They cover a wide range of subjects and reveal anew his astounding resourcefulness and originality. While not a few of the views here expressed are still discussed and contested, there can be no doubt that the discussion of such fundamental questions, as the origin and present state of sidereal bodies, has profoundly influenced and greatly stimulated the scientific thought of our time. The more popular book, "Worlds in the Making," published more recently, gives a fascinating summary of the subject, from Arrhenius' point of view. Among the many new conceptions introduced by Arrhenius into the study of cosmogony is that of the rôle he ascribes to the pressure of light in cosmic changes. He points out that the potency of this agent increases with the degree of division of matter, and thus becomes a most important factor in the phenomena of cosmic dust, nebulæ, the aurora, comets' tails, etc. His views on the origin and distribution of life are likewise interesting.

Another subject to which Arrhenius has made original and valuable contributions is that of serum therapy. It is to him that we owe the explanation of phenomena of the antitoxins discovered by Ehrlich, namely, that they are due to unstable compounds whose existence depends upon concentration equilibria, similar to those which govern weak acids and bases. The action of toxins and antitoxins thus becomes intelligible.

Mr. President, I realize that this brief sketch of Arrhenius' contributions to science touches only a few of the high lights of his achievements. It may suffice, however, to indicate that by stressing the great synthetic factors of science, this genius was enabled to open up new and fruitful avenues of research to chemistry, physics, meteorology, astronomy and medicine. We revere him as one of the foremost leaders of scientific thought of our time, and hosts of pupils and collaborators do homage to his inspiring leadership. He has wielded a powerful influence upon the scientific life of all countries, being preëminently an international scientist. His achievements are as familiar and as highly appreciated in America, England, France and Germany, as they are in his native land. His writings are addressed to the scientists

of all countries, and he has personally addressed the scientists of many countries, including our own, and generally in their own language.

I refrain from enumerating the many honors, distinctions and decorations that have been bestowed upon him. We rejoice that our beautiful Franklin Medal is now also to be conveyed to him, and that he has so appreciatively cabled his acknowledgment of the award.

I have the honor, Mr. President, to present to you Mr. Joen de Lagerberg, of the Swedish Legation, Washington, who on behalf of His Swedish Majesty's Government, will accept from you The Franklin Medal for Professor Svante August Arrhenius.

The President then said:

Mr. Lagerberg: The Franklin Institute is honored by the presence of a representative of the Swedish Government at this, one of its stated meetings, and I have been instructed by the Board of Managers of the Institute to assure you of their high respect for yourself and for the Swedish Minister, and of their gratitude that you have come to take a part in our ceremony.

Mr. Lagerberg, I have the honor, in the name of The Franklin Institute, upon the recommendation of its Committee on Science and the Arts, to present to you, for transmission through the State Department of your Gracious Sovereign, to Professor Svante August Arrhenius, the Franklin Medal and Diploma and the Certificate of Honorary Membership in The Franklin Institute.

This award is made to Professor Arrhenius in recognition of his distinguished services to mankind rendered in the field of science, and it is the highest honor in the gift of The Franklin Institute.

Mr. Joen de Lagerberg, Secretary of the Swedish Legation, in accepting The Franklin Medal on behalf of his Government for Professor Arrhenius, said:

Mr. President: Naturally it would have given my chief, the Swedish Minister, extraordinarily great satisfaction to have been able to act, at the festivities to-day, as interpreter of the feelings of pride and pleasure which fill all Swedes, in the Mother-country as well as on this side of the Atlantic, because of the honor which

has been bestowed on our great countryman, Professor Svante Arrhenius. It is self-evident that only a serious illness could have prevented him from heeding your amiable call and to have forced him to entrust to another the commission of accepting in the name of the Swedish Government, and on behalf of our illustrious countryman, your beautiful Franklin Medal—a distinction which to the whole world can only mean that Doctor Arrhenius is proclaimed one of the most eminent living scientists.

The work and scientific achievements of Doctor Arrhenius have already been set forth vividly and completely by Doctor Keller, and I shall not repeat them.

However, I could perhaps accentuate one of the features of my great countryman's character, a feature that is a very strong, if not the predominating characteristic of our race, the feature to which we owe that our name has been everlastingly inscribed in humanity's annals. I mean the desire for, even need of adventure, the longing to explore the unknown; in other words, the Viking instinct—Arrhenius is a Viking of thought, a chief among our Vikings of science.

The same love of adventure that prompted Rolf to set out for the coasts of Normandy; the same love of adventure that made Charles XII accomplish fable-like feats in warfare, and the same love of adventure that has prompted hundreds of thousands of our countrymen to come to this great land of the future, has prompted Arrhenius to explore and advance, and advance and explore in the unlimited land of the Universe.

Nothing could more vividly explain what I try to say than the epical titles of his works:

"Worlds in the Making."
"Life of the Universe."
"The Destinies of the Stars."

If in this connection I might be permitted to speak in my own name it would be only to mention how gratefully I remember the opportunities I had as a school-boy to listen to his wonderful lectures. Through him my generation, and generations to come, learned that science is more wonderful than any fiction, and that the very gates of the magic land of imagination, which, for instance, Wells pictures in his most daring works, sooner or later open at the pronunciation of "Open Sesame" by science.

There is something symbolic in the fact that the land which has so irresistibly drawn toward it, yes, to it, the Viking spirit

of so many of Sweden's sons, the land which itself among the peoples of the world represents the youthful striving toward the adventure of the future, has laurel-crowned this bold traveller in the future-land of science.

May this beautiful token of honor, The Franklin Medal, be another seal of the warm friendship that has always bound our two countries together and which friendship grows stronger each day in the measure that human cultivation, so eminently represented by The Franklin Institute, tears down the barriers which time and space have placed between us.

Mr. Charles Day, Vice-President of the Institute, then read the following paper prepared by Sir Charles A. Parsons:

SOME REMINISCENCES OF EARLY DAYS OF TURBINE DEVELOPMENT.

BY

SIR CHARLES A. PARSONS, K.C.B., C.B., M.A., LL.D., D.Sc., F.R.S.

ON previous occasions it has, I believe, been sometimes customary for the recipient of the honor of The Franklin Medal to give some account of his past history, and I will, therefore, now endeavor to give a few reminiscences which may be of some interest. I was educated on what is called among engineers the sandwich system. My father had a rooted objection to public school education, and consequently, with my brothers, I was taught by tutors at our home in Ireland. Concurrently I had the advantage of working in well-equipped workshops where my father had constructed his telescopes, and from him I learnt the first principles of mechanics and engineering, for he was a skilled engineer as well as a scientist and an astronomer. After that were interposed five years of pure and applied mathematics, including the Cambridge Tripos; and I recall that the strain was more severe than I have subsequently experienced in business life, and luckily for me, boat racing interfered with reading. In 1876 I entered Sir William Armstrong's Elswick Works as a premium apprentice, and served three years; during this time I learned from Sir William Armstrong and his staff the methods of mechanical research and construction that have made the works famous throughout the world, as the introducers of hydraulic machinery and subsequently also as constructors of guns and warships, methods closely analogous to those which the

workers in Physical Science have followed from the time of Faraday, methods which have resulted in the enormous developments in Science that have taken place in modern times. In those days I was immensely impressed by Sir William Armstrong's mechanical genius, the layout of his experiments. and his judicial selection of the fittest. and perhaps above all, by his extraordinary attention to minute details in critical cases of difficulty, while ordinary general administration he deputed to others. When he was busy with a difficult problem he concentrated his attention on it alone, and his powers of mechanical diagnosis were truly remarkable. When I recall these facts, and that he excelled Whitworth in the battle of the guns, I picture him as the cleverest mechanical engineer I have ever known. In later years, in my own business, I have endeavored to follow the same methods and principles, and have made many more failures than successes (numerically speaking) in the effort to progress as my tecahers had done before me, yet the failures should and have been soon discerned and force concentrated on the successes. When I commenced to work on the steam turbine in 1884, with the hope of making it a practical success, it seemed to me, in spite of the fact that many had previously failed in their endeavors, that it was right in principle, and that after a thorough experimental investigation it should be possible to realize success. In short, I thought it was worth trying; encouraging results followed; one improvement led to another, and it gradually became an efficient motor. When it had beaten a compound engine at driving a dynamo, my old friend, Doctor John Bell Simpson, said to me one day, when we were out shooting, "Why not try it at driving a ship?" to which I replied that I thought the time was ripe for the attempt. This was the beginning of the marine turbine in 1893, and of a strenuous time. First of all, the experimental stage was successfully completed by 1897, sufficient capital having been provided at the start; and here incidentally I recall with gratitude the kindness of the Tyne Commissioners, who did not prohibit the *Turbinia* from making trials at 30 knots in the Tyne, whereas the speed limit was 7 knots, which saved months, for many trials were run in storms and snow, when it was impossible to run so small a vessel at high speed in the open sea. Then followed the uphill attack on the market, followed by the total loss of the torpedo-boat destroyers *Viper* and *Cobra*, the latter involving the loss of many valuable lives. This was concurrent with the time of

maximum financial stress, because both vessels had cost more than their price, but the work, in spite of this, was steadily pursued. At this juncture, the munificence of Mr. Christopher John Leyland was of inestimable help. From the commencement he had been a director. His love of work and great interest in the marine development led him to attend almost every trial trip. On the *Turbinia* I was Chief Engineer and he was Captain, a position to which his naval services entitled him, and apart from the financial side his help was great. The late Sir William White did much towards the introduction of turbines into the British Navy, and while he was Naval Constructor at the Admiralty the order for the first turbine-driven destroyer, *Viper,* was placed, and the first turbine-driven cruiser, *Amethyst,* was requisitioned. Sir Philip Watts also strongly advocated the turbine when he was at Elswick, and afterwards when Chief Constructor at the Admiralty; but the general introduction of the turbine in the Navy soon afterwards was primarily due to the success of the *Amethyst* and to the enterprise of the British Admiralty themselves, who, in this field, as well as in others, have been pioneers among the nations. My old friend, Sir Archibald Denny, was one of the first to recognize the advantage of the turbine for cross-channel steamers, and induced his firm to join with Captain John Williamson and our Company to build and start the first mercantile turbine steamers on the Clyde. But from this brief account I must not omit to mention one other name, that of my old friend, Dr. William Garnett, who, when Principal of the Durham College of Science in Newcastle, took a great interest in turbines, and who was chiefly instrumental in inducing the authorities to use turbines exclusively for the lighting of the Newcastle Exhibition of 1887; and, lastly, I should mention that the great factor for success, as is necessarily the case, has been the enterprise, hard work, skill and loyal coöperation of the directors and staffs of our land and marine works, and that in my colleagues I have been extremely fortunate. Though we have had some trying times, work has almost always been a pleasure, and I feel that I owe more to them than I can well express. In closing, allow me again to say how deeply I appreciate the great honor you have conferred by awarding to me The Franklin Medal.

Dr. Allerton S. Cushman then read the following paper for Professor Arrhenius:

THE PROBLEM OF THE WORLD'S SUPPLY OF ENERGY.

BY

SVANTE AUGUST ARRHENIUS, Ph.D., M.D., D.Sc., LL.D.

SINCE the days of Watt the physical well-being of mankind has become more and more dependent on fossil fuels. The life of to-day would be impossible without the enormous supply of coal necessary to industrial establishments, for railways and steamships, in the metallurgical arts and for the heating and lighting of our houses. The demand for fossil coal has increased very rapidly, about doubling every ten years during the last century, and is now some 1200 millions of metric tons per year. It is clear to those who have studied the matter that our coal fields will be exhausted after a certain time. When this calamity will happen, and the probability of the discovery of substitute sources of energy, are questions of vital importance.

One of these questions was answered by the Geological Congress in Canada in 1913. The quantity of fossil coal down to a depth of 1800 metres would suffice for 6000 years, at the present rate of consumption, if it were all recoverable, but a very great deal of this coal occurs in beds too thin for profitable working, a considerable part is lost as dust, or left in the mines as pillars, and further, the use of coal will probably increase in the future just as it has done in the past. It is, therefore, necessary to reduce the indicated time considerably, probably to one-fourth, or about 1500 years.

Of the different countries the United States, in the matter of coal, has the best position, as it has in the matter of other natural resources. The coal treasures there will probably suffice for about two thousand years. The worst situation among the great coal-producing countries is that of England, where the coals will be exhausted within a little less than two hundred years. Germany will be able to meet its demands during a little more than a thousand years.

This time of some few hundreds or thousands of years is very short compared with the time estimate made at the Geological Congress referred to, and only about one per cent. of the period of man's existence, which probably lies between the thousandth and ten-thousandth part of the time during which life

has existed on our earth. It is quite clear that we must soon ration our coal, and substitute as far as possible for fossil fuel other sources of energy.

It is often suggested that we might use mineral oils as fuel instead of coals. This advice rather reminds one of the words of Marie Antoinette: "If the people complain that they have no bread to eat, why do they not eat cakes?" Petroleum is a far more valuable fuel than coal, because it is much easier to transport and to use effectively. The world's yearly production of mineral oils represents not quite three per cent. of the energy contained in the yearly production of coal. Petroleum ought, therefore, to be reserved for better purposes, *e.g.*, production of light and lubricants. Further, the recent failure of many oil fields indicates that we must economize this valuable material. According to David T. Day, U. S. Geological Survey, the production per well in the Appalachian oil field decreased from 207 barrels in 1861 to 1.73 barrels in 1907. The production of West Virginia had, in 1910, declined 56 per cent. from its maximum output. The oil obtained from the New York and Pennsylvania oil fields fell to 50 per cent. from the year 1891 to 1898. If we suppose the present fields of the United States and the present rate of exploitation should continue, petroleum would be exhausted by about 1935, and if the present production goes on with no increase, the product would be exhausted in about ninety years, said Charles R. van Hise in 1910, who has done so much to warn against waste in the expenditure of our natural resources. The output of mineral oil has been kept up through an enormous increase in the number of oil wells in each field, and by opening up new fields, *e.g.*, in Oklahoma and California. There are very rich new oil fields in the world which are still not used, or only in a small degree, *e.g.*, in Mexico and Mesopotamia and Turkestan, but certainly they will not last as long as the coal fields, even if the production of this fuel is restrained to but three per cent. of the simultaneous production of the latter.

Still much less is the hope that sources of natural gas may deliver more than a small fraction of the fuel value of the oil fields. Even peat, although an important fuel, can by no means compete with coal. Thus, for instance, in the United States the available peat is less than one-half of one per cent. of the estimated coal. Probably the relative value of the European peat

bogs is about the same as compared with the European coal fields. For heating purposes petroleum and peat cannot play an important rôle as compared with fossil coal.

It is very often said that for coal should be substituted the water power of our rivers, often called the "white coal." According to an estimate of Engler, the energy which might be economically taken out from these waterfalls amounts to about 60 per cent. of the energy of the present output of coal. But even this figure seems too high, for many of the waterfalls are located in rather inaccessible parts of the world, where no industry is likely to be developed for a long time. So it seems wise to reduce the figure of Engler about 50 per cent. If this is done, it is evident that there is little hope that white coal will be able to substitute for black, except in a small degree. For heating purposes water power will probably not be used in a noteworthy degree, because used directly for the production of mechanical or electrical energy it is at least three times as valuable as the equivalent quantity of heat. Further, the well-situated waterfalls are already developed in greatest part, at least, in Europe. Thus, for instance, in Switzerland nearly all the waterfalls which have a commercial value are developed, and in a little less degree the same is true in all the other industrial countries of Europe.

During the unhappy situation created by the world war, when there was a great scarcity of fuel, and even now, when fuel is extremely expensive, waterfalls were and rapidly are being put to use. Within a short time, therefore, this source of energy will be taken into the service of man, not sensibly diminishing the demand for coal. An estimate of the power of the waterfalls has been made by Koehn and by Keplan, and is of much interest. Although the figures are only approximate, I give them below, with some later corrections. The power is given in millions of horsepower and horsepower per inhabitant:

Country	Horsepower in Millions		Horsepower per Inhabitant
Asia	236		0.27
Africa	160		1.14
North America	160		1.17
South America	94		5.25
Europe	65		0.13
Australia	30		3.75
Total	745	Average	0.45

Country	Horsepower in Millions	Horsepower per Inhabitant
Canada	26	4
United States	100	1
Iceland	2	22
Norway	13	5.2
Sweden	6.7	1.2
Finland	2.6	0.8
Balkan Countries	10	0.6
Switzerland	1.5	0.4
Spain	5.2	0.26
Italy	5.5	0.15
France	6.0	0.15
Austria-Hungary	6.2	0.12
Germany	1.43	0.02
Great Britain	1.0	0.02
Russia	3.0	0.02

These figures are not altogether reliable. Thus, for instance, Leighton gives for the United States 200 millions, and van Hise says: "Others regard this estimate as too high, and say 100 million horsepower is nearer to truth." I think this latter figure is more to be depended on. Van Hise is of the opinion that even it will meet the needs of a population of 250,000,000. Since his estimate made in 1910 the demands for power have greatly increased, and probably only about one-half of the energy given in the table above is available at present without excessive initial expenditures. We may, therefore, assume 0.5 horsepower per inhabitant as adequate to present needs. We find then that Europe and Asia are the only parts of the world where water power is really scanty—in Asia the demand is still so small that even this power per inhabitant is more than sufficient. Especially fortunate are those countries, such as South American Republics, and Australia, where water power per unit of population is well beyond this figure, and may be developed at a moderate cost. The United States is among the great powers very well endowed in this regard, as in most other natural sources of wealth, such as metal, ores and coal. In Europe, Iceland ranks first, because of its small population, and the old Saga Island may yet know a new and flourishing era. Then come the Scandinavian countries, the first being Norway, which has already greatly profited through its cheap power, and is destined to be one of the leading industrial countries of the future. Sweden and Finland possess enough power for their needs. Their waterfalls are not high, and in

general are far from established lines of communication, especially from those of the ocean. Denmark has scarcely any water power, as also Holland. Among the other countries of Europe the Balkan States have more power than their industrial needs require. Switzerland may also be regarded as having a nearly sufficient supply of water power, which is the more fortunate, as this highly industrial country does not own any coal deposits. The same is true of the new Austria, which has lost its old coal districts but has retained by far the greater part of the waterfalls of the old Austria, so that it now probably ranks with Switzerland in this respect. Spain is also a relatively well situated state, but which up to the present has not made much use of its resources. In general, the waterfalls in the Alps, Spain, Italy and the Balkans are high and of great value. For the industries of France and Italy water power is of the greatest importance, although it must be regarded as insufficient for nations so highly developed. At the end of the list come the three great powers of Great Britain, Germany and Russia, with only a fiftieth horsepower per inhabitant. Russia is an agricultural country, with a very small demand for power, and agriculture will probably remain its chief industry because of its small power resources, both in coal and water. England and Germany, now the most highly developed industrial countries in the world, will undoubtedly also, in the future have agriculture for their chief industry. Probably a great part of these countries will again be covered by forests, as they were in the time of Tacitus.

It is often asserted that the power of tidal waves should be utilized. Of course, this is possible, but doing so on a large scale would involve an initial investment not justified by prices likely ever to be obtained for power. The energy of the tidal wave is so widely distributed along the shores of the oceans that it is impossible to commercially collect a sensible part of it. It is quite in contrast to the energy of fossil fuel and waterfalls.

All available energy on the earth has its origin in solar radiation. Of this energy a small part, 0.12 per cent., is accumulated in vegetation, which, however, is great as compared with the energy of the coal burned in the industries. A detailed calculation, made by Professor Schroeder, of Kiel, shows that about twenty-two times as much energy is yearly accumulated in plants as is represented by the coal consumed in the same time. Of this energy

in vegetation 67 per cent. is taken up by the forests, 24 per cent. in cultivated plants, 7 per cent. in the grass of the steppes and 2 per cent. on desert lands. The energy collected by forests may be used for heating purposes, and exceeds every year that of the coals burnt by about fourteen times. But, unhappily, the greater part of this energy is collected in tropical areas, and the highly cultivated countries are so nearly deforested that their production of wood is not nearly sufficient as fuel for their industries. Further, the wood produced in civilized countries is needed for the production of paper, pulp and lumber. In forest lands the refuse from the woods may be sufficient for domestic purposes, and during the war even the industrial needs of certain countries for combustibles were met by wood, where the importation of coal was hindered by the blockade. The costs, however, were very high, due to the expensive transport from the forests to the industrial centres. The transport of wood from the immense forests in the tropics to industrial countries seems impossible on economic grounds. The forest lands possess, therefore, an advantageous position in this regard. Before other industrialized countries will be able to substitute wood for coal an economic sclution of the transportation problem is necessary, which at present seems fraught with exceedingly great difficulties.

Two other sources of energy, greatly dispersed in form, remain to be considered, namely, those of the winds and of sunshine. They are extremely great, and exceed that of simultaneously burnt coal from 5000 to 70,000 times, respectively. The energy of the winds is taken up by windmills, which have been in use in Europe since the eleventh century. The great objection to wind as a source of power is its variability, and the high installation costs per unit of power continuously deliverable. It has been proposed to store the energy of the wind by means of accumulators, charged from windmills, and to use these accumulators during times of calm. But even in windy countries, *e.g.*, Denmark, this method is extremely uneconomical, as compared with coal or wood at their present price. Windmills are widely used for pumping water, both in the new and the old world.

The radiation of the sun may be concentrated by means of mirrors on a boiler, and this connected to a steam engine. The best known of these solar engines was constructed by John Ericsson, and described in *Nature* in 1888. It was an improve-

ment of an earlier machine constructed in 1860. In his experiments in New York, John Ericsson obtained an effect of one horsepower with a mirror of ten square metres' opening. Later, his experiments were taken up on a commercial scale by Mr. Shuman, of Philadelphia, who installed a solar engine, with mirror of 1200 square metres in all, at Meads, 10 kilometres south of Cairo, in Egypt. The machine was of the Ericsson type, with some small modifications, and auxiliary apparatus. Shuman did not obtain more than half the effect of that obtained by Ericsson, namely, one horsepower per twenty square metres mirror opening. After an inspection of Mr. Shuman's plant, Mr. Ackerman thought it possible to introduce improvements which would give as good results as those obtained by Ericsson.

After improvements the solar engine seems likely to play an important rôle in the opening up for cultivation of great arid districts in tropical countries, as Ericsson maintained with great energy it would do. In these parts of the world are great deserts, such as Sahara, the Arabian desert, the Syrian desert, and those in Mesopotamia, which have in historical times been the seat of flourishing culture, but are now the home of wandering tribes. The decay of these regions resulted from the destruction of their aqueducts and irrigation plants, which the present wandering population is unable to restore. With the aid of the solar machine it would be possible to re-establish the old agriculture and horticulture of these districts, and industrial works founded on its use might also be looked forward to. It is not only in the deserts that the sun is shining nearly continuously during the greatest part of the year, but extensive provinces in Spain, Greece and North America possess such a climate that they would profit by the introduction of the solar engine. In other parts of the world, where the sky is covered for the greatest part of the year, as in the Congo or the Amazonas, or which lie nearer to the poles, as the temperate regions, the solar machine will be of very little use.

It seems very probable that when fossil fuel has been consumed, civilization and culture will return to its birthplace about the Mediterranean and in Mesopotamia in the old world, and to Central America and the land of the Incas in the new.

According to some calculations made by me an increase of the carbonic acid in the atmosphere will give the whole earth a more uniform and warmer climate. Therefore, we may suppose

that the burning of coal will cause our climate to approach to that of the tertiary age. Furthermore, vegetation is highly stimulated through absorption of carbonic acid in the soil, augmented through an increase of the carbonic acid in the air. It is, therefore, probable, as I have tried to show in my book, "World's in the Making," that the total consumption of the available coal by the industries will, in a high degree, favor agriculture and the growing of forests in the temperate regions now the chief seat of culture. These regions will then know not only harmful, but some useful consequences as the result of the present waste of our fuel resources.

STOCKHOLM, NOBEL INSTITUTE, April 19th, 1920.

Light Scattering by Air and the Blue Color of the Sky. R. W. WOOD. (*Phil. Mag.*, April, 1920.)—The depth of a layer of air in full sunlight, with a black cave as a background, which would give a luminosity equal to 5 per cent. of that of the blue sky 60° from the sun on very clear days, was found to be 1000 ft. On slightly hazy days it was 400 ft. The air near the earth with its large load of dust has a scattering power 2.6 as great as the average scattering power of the entire atmosphere. When air carefully freed from dust is traversed by a beam of sunlight it is found that the quantity of light scattered at right angles to the beam is about equal to that scattered in the direction of the beam. If the entire thickness of the atmosphere were free of dust we should therefore expect to find no such great increase in brightness in the sky near the sun, as is observed under the present conditions. Modern experiments confirm Lord Rayleigh's attribution of the blue color of the sky to the effect of scattering by air molecules themselves without assistance from dust particles.

G. F. S.

The Great Potash Deposits of Germany. (*U. S. Geological Survey Press Bulletin, No. 443*, April, 1920.)—The potash deposits of Germany, which were discovered by the Prussian Government in 1843 at Stassfurt while boring for rock salt and which occur in upper layers of rock salt in the plains of northern Germany, have been estimated to occupy a volume of 10,790,000,000 cubic meters and to contain 20,000,000,000 metric tons of potash salts, corresponding to about 2,000,000,000 metric tons of potash (K_2O), a quantity sufficient to supply the world for two thousand years at the present rate of consumption. These beds, according to the United States Geological Survey, Department of the Interior, were first exploited about 1860, and have furnished practically the entire world's supply of potash for many years.

Casting and Treatment of Steel. J. H. ANDREWS. (*North-East Coast Institution of Engineers and Shipbuilders,* April 16, 1920.)—The paper deals with metallurgical research as applied to steel and with its uses and applications to engineers. The question as to what defines a good and a bad casting, and how each type can be obtained, is used as a basis and the following points are considered: High casting temperature and the effect of temperature upon skeleton crystalline structure; "chill" crystals, "dendrites," and "onion" crystals; Mr. Humphrey's method for distinguishing the high and low phosphorus parts of an ingot.

The author asserts that the only way in which to derive the most suitable treatment for any steel is to take a recalescence curve and carefully note the temperatures of the critical point or points. Actual heating curves of a number of steels are reproduced and discussed. The author's conclusions are that the mechanical properties of a steel depend primarily upon the degree of fineness of the structure; the means of obtaining this are summarized. The effect of manganese on the properties of steel is considered. The results of experimental impact tests upon a series of nickel steels are given.

The paper concludes with a few remarks upon the application of the microscope to metallurgical work.

Effect of Solution Reaction on Germination and Growth. (*Jour. Agric. Research,* 1920, vol. xix, 73.)—R. M. SALTER and T. C. MCILVAINE, of the W. Va. Agric. Exp. Sta., report the results of many experiments very carefully made to determine the influence of hydrogen-ion and hydroxyl-ion concentration in soil-solution on the germination and growth of wheat, soybean, corn, red clover, and alfalfa. Some of their conclusions are:

Maximum growth of seedlings of wheat, soybeans, alfalfa, and red clover occurred in cultures having a hydrogen-ion concentration of 5.94 P_H, while corn showed the best results with a concentration of 5.16 P_H.

A reaction of 2.16 P_H was fatal to all seedlings in a short time and favored the growth of molds.

The hydroxyl-ion was apparently more harmful in equivalent concentration than the hydrogen-ion.

No indication of any harmful effect of a member of the monophosphate (H_2PO_4)[1] other than that produced by the hydrogen-ion formed by its dissociation.

Germination of the seed was found to be less affected by an acid reaction than the subsequent growth of the seedling.

The optimum reaction for the germination of the five seeds studied is probably below 7.71 P_H and above 2.96 P_H, a slightly acid reaction being found favorable in all cases.

H. L.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

A NOTE ON STRESSES CAUSED BY COLD ROLLING.[1]

By H. M. Howe and E. C. Groesbeck.

[ABSTRACT.]

THE experimental data here presented show that a given amount of reduction by rolling causes less residual stress in the metal rolled if it is brought about by a large number of light drafts than if by a smaller number of heavy ones. This is shown by means of the curvature induced in each of a pair of superposed strips when they are simultaneously reduced in thickness by rolling, with varying reductions.

The result is attributed to the greater skin friction between the metal rolled and the face of the rolls with heavy than with light reductions. Because of this greater skin friction more of the reduction occurs through the backward forcing of the deeper-seated layers, and less through the elongation of the surface of the metal in contact with the rolls.

REFLECTING POWER OF MONEL METAL, STELLITE AND ZINC.[2]

By W. W. Coblentz.

[ABSTRACT.]

DATA are given on the reflecting power of monel metal, stellite and zinc in the visible and in the infra-red spectrum. The reflectivity of monel metal is practically the same as that of nickel, except in the short wave lengths where the reflective power is somewhat lower than that of pure nickel.

A new determination of the reflectivity of stellite gave values about 1 per cent. lower than previously observed in the visible spectrum, see B. S. Sci. Paper No. 342. The reflectivity of zinc is unique in having a deep minimum as 1μ followed by an unusually high value beyond 2μ.

* Communicated by the Director.

[1] Technologic Paper No. 163.

[2] Scientific Paper No. 379.

OPERATION AND CARE OF VEHICLE TYPE BATTERIES.[3]

[ABSTRACT.]

THE preparation of this circular was begun by the Construction Division of the Army, using as a basis the results of tests made on tractor batteries at the Bureau of Standards. The circular contains a description of both the lead-acid and the nickel-iron types of batteries with the elementary theory of operation. Performance curves for both types are given showing the characteristics of constant current and constant potential charging, and for discharges at the normal 5-hour rate and at five times this rate. Later sections of the circular discuss the subjects of capacity, voltage, resistance, methods of testing, methods of charging, and directions for repairing lead-acid batteries. Appendices A and B contain War Department specifications for batteries of this type and for charging equipment. Appendix C gives record forms to be used in maintenance and Appendix D outlines the method of computing costs of operation. Appendix E is a glossary of terms used in connection with storage batteries.

THE SAYBOLT VISCOSITY OF BLENDS.[4]

By Winslow H. Herschel.

[ABSTRACT.]

IT has long been recognized that the viscosity of a mixture or blend of two oils is less than the arithmetical mean between the viscosities of the component oils. This is true whether viscosities are expressed in Saybolt seconds, poises or any other known unit of viscosity. For definite chemical compounds which are inert with respect to each other, a formula has been found which gives the viscosities of mixtures with great accuracy, but this formula can not be used with oils for which the molecular weights are not known.

For the purpose at hand the best available formula was found to be

$$\log \mu = v_1 \log \mu_1 + v_2 \log \mu_2 \qquad (1)$$

where μ, μ_1 and μ_2 are the viscosities, in poises, of the blend and of the two component oils, and v_1 and v_2 are the percentage volume

[3] Circular No. 92.

[4] Technologic Paper No. 164.

concentrations. Expressed in words, equation (1) shows that the viscosity of a blend is the weighted geometrical mean between the viscosities of the component oils, that is, the logarithms of the viscosities are additive.

If it is assumed that a Saybolt viscosimeter is used, the viscosity in poises may be obtained by the formula,

$$\mu = [.00220\, t - (1.80/t)\,]\,\gamma \qquad (2)$$

where t is the time of flow, or Saybolt viscosity, in seconds, and γ is the density of the oil at the temperature of test, in grams per cubic centimetre.

It was found that the viscosities of blends as determined by test, agreed in some cases fairly closely with the viscosities estimated from equations (1) and (2), but the estimated value was always too low when there was a considerable difference between the viscosities of the component oils. For given component oils, the error increased as the amount of the lighter oil increased, reaching a maximum in a blend containing about 60 per cent. of the lighter oil. It was also found that the per cent. of error varied with the source of the crude oils, the maximum error being obtained if a heavy naphthene base oil was blended with a light paraffin base oil, and the minimum error being found with a blend of heavy paraffin and light naphthene oils.

In order to carry the difference in viscosity to an extreme, a heavy naphthene base oil was mixed with aviation gasoline, and the error in estimating the viscosity of the blend was found to be 221 per cent. But even in this case the viscosity determined by experiment was not as low as would have been estimated on the assumption that the reciprocal of viscosities was additive, a rule sometimes advocated as the true law of mixtures. Within the range of viscosities actually employed in blending operations, it was found that the maximum error in the viscosity calculated from the logarithmic rule would be 33 per cent. for naphthene base oils, or 25 per cent. for paraffin oils. A diagram was obtained for estimating the correction factor to be applied to viscosities of blends as calculated from the logarithmic rule. It is believed that with the help of this diagram the viscosity of a blend may be estimated with an error not greatly in excess of the error in determining the viscosity of the component oils.

Development of Ferro-vanadium Metallurgy.—B. D. SAKLATWALLA, general superintendent of the Vanadium Corporation of America, presented at the last (37th) general meeting of the American Electrochemical Society (April 8–10, 1920) a paper on this subject, which is interesting as showing how a metal which in earlier days had almost no applications is now of great importance in the industry. The chemical manuals of fifty years ago had little to say about vanadium compounds, except their possible use in making ink. Now vanadium steels are of extended use in several lines. Vanadium was, in common with several other elements, incorrectly classed as "rare." The real difficulty was the lack of any known deposit in large amount at one place. The metal is, indeed, one of the most widely distributed elements. It is diffused through all primitive granites and many sedimentary rocks and clays. Apart from the minerals in which it is the main constituent, it is found as an accessory in nearly three-score other minerals.

The discovery of a large deposit near Cerro de Pasco, in the Peruvian Andes in 1905, enabled the development of the vanadium alloys to be undertaken with greater success than previously. The chemistry of vanadium owes much to Berzelius, but the first suggestion of its application to metallurgy dates back to 1863, when Lewis Thompson suggested that it might affect iron in somewhat the same way that nickel does. The actual technical use, commercially, of vanadium steel began in 1896, when the Firminy Steel Works in France experimented with it in armor plates. Further researches continued; in 1904 Sankey and Smith published their investigations, and by a fortunate coincidence the Peruvian deposit was found shortly afterwards.

The author of the paper describes processes of manufacture of special steels and also the difficulties of obtaining the pure metal.

H. L.

The Largest Rolling Mill in the World. (*Electrician*, May 7, 1920.)—This distinction is claimed for the electrically driven, 20,500 h.p. installation recently put in service at Messrs. Dorman & Long's new Warrenby mills not far from Durham, England. It is a 42-inch plate mill, reversing type. Each roll is 3 ft. 6 ins. in diameter and 9 ft. 6 ins. long. Slabs weighing 10 tons with dimensions up to 7 ft. by 4 ft. 6 ins. by 1 ft. 6 ins. can be handled. Such slabs are rolled into plates three-eighths inch thick or over and attaining a width of 9 ft. and length of 100 ft. For two hours the output is 60 tons per hour; after this it is half as much for the remainder of the shift. The motor driving the rolls weighs 420 tons and the revolving parts 120 tons. In less than three seconds it can be reversed from 40 r.p.m. in one direction to the same speed in the opposite direction.

G. F. S.

NOTES FROM THE RESEARCH LABORATORY EASTMAN KODAK COMPANY.*

A STUDY OF THE SULPHUR DERIVATIVES OF BUTYL ALCOHOL.[1]

By H. LeB. Gray and Gurney C. Gutekunst.

[ABSTRACT.]

BUTYL SULPHIDE is prepared from butyl alcohol by first preparing sodium butyl sulphate and then distilling the crude reaction mixture with sodium sulphide. Butyl mercaptan is formed in large quantities by this method. The formation of butyl mercaptan is eliminated by refluxing the mixture with a large excess of sodium hydroxide and then distilling: a 72 per cent. yield is obtained. Butyl sulphide is also prepared by refluxing a mixture of butyl mercaptan and sodium butyl sulphate with a large excess of sodium hydroxide.

Dibutyl ether is prepared from butyl alcohol by refluxing a mixture of the alcohol and concentrated sulphuric acid at boiling temperature for 15 hours. Good yields are obtained by this method.

Butyl sulphide was oxidized to butyl sulphone by two methods. Oxidation by means of fuming nitric acid requires a large excess of the acid and a very impure product is obtained. The method of purification is long and tedious, and the yields obtained are very unsatisfactory. Butyl sulphone may be obtained in very small yield by oxidation of butyl sulphide with nitrogen dioxide. Oxidation of the sulphide with sodium permanganate was very successful. In this method the permanganate was added in small portions to the butyl sulphide with mechanical stirring. Large quantities of manganese dioxide separate. A 25 per cent. solution of sulphuric acid is added from time to time. The oil separating at the end of the reaction is poured off and the residual manganese dioxide extracted with ether. The oil obtained solidifies on cooling and is broken up and centrifuged. Practically pure butyl sulphone is obtained. One crystalization for alcohol is sufficient for purification.

* Communicated by the Director.

[1] Communication No. 85 from the Research Laboratory of the Eastman Kodak Company, published in *Jour. Am. Chem. Soc.*, **42**, p. 856, 1920.

TESTS OF X-RAY INTENSIFYING SCREENS.[1]

[ABSTRACT.]

FROM a practical standpoint, the most important characteristics of an X-ray intensifying screen are speed (intensifying factor), definition and graininess. The most reliable determination of intensifying factor was found to be by making exposures of parts of the human body, under the ordinary conditions of radiography, the intensifying factor being the ratio of the exposure without screens to the exposure with screens to give the same average density of negative. The intensifying factor varies with both the intensity and quality of the incident X-radiation; and for this reason, exposures made in a sensitometer or by any similar method, do not usually give the same factor as is obtained in practice. Slightly higher intensifying factors are obtained for thinner parts of the body than for the thicker parts. Double screens give much more contrast than single screens. Single screens give but little more contrast than is obtained upon films alone. Whether or not a double combination is faster than the single screen depends upon the properties of the screens and upon the intensity and quality of the X-rays striking the screen. The graininess of a screen may be tested by a flash test, giving a half-tone density on the film when given standard development. The definition of screens may be compared by making radiographs of a 200-mesh wire gauze. Some screens show the meshes quite well while with others the meshes can scarcely be distinguished. The meshes are shown most clearly by the use of X-ray film without screens. A screen used as a double screen gives poorer definition than when used as a single screen. All these tests were made with no scattering material between the X-ray tube and the film. The wire screen test applied to the entire area of screens in cassettes showed loss of definition at the corners and edges, due to lack of contact of the screens with the film. Cassettes should give uniform pressure over the whole area of the films and screens should be sufficiently flexible to be flat under the pressure in the cassette.

[1] Communication No. 76 from the Research Laboratory of the Eastman Kodak Company, published in *Amer. J. Roent.*, vii, 1920, p. 196.

NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

THE FOOD OF THE SMALL SEA HERRING AND AMMONIA AND AMINES AS END PRODUCTS OF ITS DECOMPOSITION.[1]

By F. C. Weber and J. B. Wilson.

[ABSTRACT.]

THE copepods, chiefly *Calanus finmarchicus, Pseudocalanus elongatus,* and *Temora longicornis,* and schizopods (shrimp) constitute the chief forms of feed of the small sea herring of the Passamaquoddy Bay region.

Very appreciable quantities of ammonia and amines were found when these forms of fish food were allowed to decompose. These products of decomposition were formed also when the two bacteria, *Bacillus Walfischrauschbrand* and *Bacillus B.,* associated with the feed were grown in pure culture. Skatole and indole as well were present in the culture media on which these bacteria were grown. Moreover, the presence of ammonia and amines was detected in the contents of the digestive tracts of "belly-blown," feedy fish.

From these results it may be concluded that the formation of ammonia and amines in the decomposing food is due to the action of the two bacteria always associated with the copepods and schizopods, whether they are taken directly from the water or from the digestive tracts of the fish.

Decomposition of the feed, accompanied by the evolution of gas when *Bacillus B* is present, is responsible for the bursting of the bellies of "feedy" fish.

THE MICROSCOPICAL EXAMINATION OF FLOUR.[2]

By George L. Keenan and Mary L. Lyons.

[ABSTRACT.]

USING special microscopical technic devised for the enumeration of the offal material in flour of various commercial grades, it was found that little uniformity in the matter of grading fin-

* Communicated by the Chief of the Bureau.

[1] Published in *J. Am. Chem. Soc.,* **42,** 1920, 841.

[2] *U. S. Dept. Agr. Bull.,* **839,** issued April 23, 1920.

ished flours prevails in the different mills, and that there is a wide range in the offal content among flours of apparently the same commercial grades produced in these mills. It would seem that all mills do not composite their finished flours in the same manner. The effect on the offal content of the addition of various mill stocks may be determined by a microscopical examination of the constituent streams entering into the composition of a flour.

THE DIGESTIBILITY OF CHICKEN SKIN.[3]

By Edward F. Kohman and H. A. Shonle.

[ABSTRACT.]

Two metabolism experiments were conducted to determine the digestibility of chicken skin. Part of the fat was removed by extracting the skin with water, so that the skin, which was prepared for the experiment by being rolled into balls and fried, had a fat content of 26.3 per cent. and a nitrogen content of 3.03 per cent. This chicken skin was substituted for eggs, meat and milk in the ordinary diet of two subjects. The results showed that there was as good utilization of the nitrogen when from 65.1 to 67.5 per cent. of the nitrogen of the diet was supplied by chicken skin as when the same percentage of nitrogen was supplied by meat, eggs and milk.

PICKLE INVESTIGATIONS DURING 1919.[4]

By Edwin LeFevre.

[ABSTRACT.]

THE following results were obtained during the pickle investigations conducted by the Bureau during 1919:

1. Acid production is decidedly increased by the addition of 1 per cent. of corn sugar or molasses to the brine, corn sugar giving the best results. In the many cases where the sugar content of cucumbers is too low, the addition of sugar to the brine effects a stronger fermentation and better acid production.

2. Cucumbers fermented in a brine to which calcium carbonate and calcium sulphate, in amounts not exceeding those

[3] Published in *J. Biol. Chem.*, 41, 1920, 469–472.

[4] Published in the *Canner*, 50, 1920, pt. ii, 230–232.

found in many natural hard waters, have been added do not cure as well and the acidity is lower than when brines which do not contain these salts are used.

3. A very active fermentation and the highest degree of acidity noted in the experiments were obtained when lactic-acid-forming bacteria were added to the culture. It should be possible to secure practically the same results by adding to the tank a few gallons of brine from a freshly fermented barrel of pickles.

4. The addition of 1 per cent. of an edible form of lactic acid prevents a normal fermentation, but does not retard the curing of pickles.

5. Cucumbers of various sizes lose weight rapidly when submerged in a 10 per cent. (40°) brine, and, after remaining at the minimum for about three days, finally regain their original weight. From 40 to 60 days are necessary for this recovery in weight, corresponding very closely to the time required for a complete curing of pickles.

6. A brine of 10 per cent. salt concentration is the proper strength for starting a fermentation.

7. The length of time intervening between the gathering and brining of cucumbers has an important bearing on the formation of hollow pickles.

8. Cucumbers have a somewhat higher sugar content than has been previously indicated, the average sugar content for six varieties being found to be 2.18 per cent.

SAUERKRAUT PRODUCTION CONTROLLED BY HEAT.[5]

By Edwin LeFevre.

[ABSTRACT.]

As a result of investigations which showed that the organisms instrumental in fermenting sauerkraut require an optimum temperature of 86° F. and that these organisms fail in biochemical activity in the same ratio as the temperature falls below this temperature, experiments were conducted to determine whether it was possible under factory conditions to secure the proper degree of heat with cabbage, and, if so, how.

The suggestion that a favorable temperature might be secured by storing the cabbage in bins was disproved by a series of tests

[5] Published in the *Canner*, 50, 1920, pt. ii, 161–162.

which showed that only that portion of the cabbage which was well covered for a period of about four days was heated to any degree, by which time degenerative changes had set in. Moreover, it was found to be a physical impossibility to secure an even and satisfactory degree of heat by heating the outside of the tank containing the cabbage.

The experiments showed, however, that the heating of cabbage, with a view to promoting fermentation, may be effectively accomplished by the direct application of jets of steam to the shredded product; also that the use of an added culture of lactic bacteria aids in the fermenting process, although not to such an extent as to be considered of great practical importance.

Absorption of Arsenous Oxide by Metastannic Acid.—T. R. BRIGGS and W. J. BARTLETT (paper presented at 37th meeting, April 8–10, of the Amer. Electrochemical Soc.) have found as follows:

At ordinary temperatures metastannic acid adsorbs arsenous oxide from watery solution, the action decreasing as the temperature rises. There is no trustworthy evidence that definite arsenites are formed, and probably Reichard's basic arsenite is merely an adsorption complex. Sulphuric acid and copper sulphate do not wholly prevent the action at ordinary temperatures, but interfere somewhat.

The old Gruessner and Badt method of removing arsenic from spent electrolytes seems to be an adsorption process. The presence of other substances more readily adsorbed may account for the unreliability of the method. The physical condition of the metastannic acid will have also a great influence on the result. Adsorbed arsenous oxide has a decided peptonizing action on the acid.

H. L.

Carnotite as a Source of Uranium.—In a discussion on a paper presented by Mr. GIN at the 37th meeting of the Amer. Electrochemical Soc. (April 8–10) it is stated that pitchblende is no longer the most abundant source of uranium, the carnotite deposits of Colorado and Utah having yielded far greater supplies in the last few years. Of course, another change has taken place in regard to the status of uranium minerals. Years ago the uranium content was the important feature, but now radium is the element sought. This fact has modified the metallurgy of uranium, since any process for extracting this metal which does not involve the obtaining of the maximum of radium from the ore must be abandoned. Uranium is now a by-product and somewhat of a drug in the market.

H. L.

NOTES FROM THE U. S. BUREAU OF MINES.*

LIQUID OXYGEN EXPLOSIVES.

By George S. Rice.

THE scarcity of glycerine and ammonia during the war so affected the production and cost of dynamite and black blasting powder that the Bureau of Mines initiated experiments in the manufacture and methods of use of liquid-oxygen explosive, at its explosives' testing station at Pittsburgh, in March, 1917. After the armistice, while in Europe as member of the Commission for studying methods for rehabilitation of French and Belgian mines and works, I observed the progress made abroad with liquid-oxygen explosive. Germany was found to have used it extensively in non-gaseous coal mines, in quarries, tunnels, and for destroying French steel plants. The allied countries, being still able to import Chilean nitrates, had not used the explosive.

The Bureau of Mines obtained promising results in the preliminary experiments, and is continuing this work in the hope of making the use of liquid-oxygen explosive practical and economical in mines and quarries. As eminent physicists are promising improvements in liquifying apparatus that can be used for production of cheap oxygen, the explosive may become so cheap as to displace other explosives where conditions permit its use. Details on the use of liquid-oxygen explosive by Germany during the war, and the experimental work of the bureau are given in Technical Paper 243.

PERFORATED CASING AND SCREEN PIPE IN OIL WELLS.

By E. W. Wagy.

THE ideal condition for maximum production from an oil well is an open, self-supporting hole toward which the oil moves from all directions without any barrier to its passage. When the walls of the hole are not self-supporting, but tend to run or cave, perforated casing, known as the "oil-string," must be used. In

* Communicated by the Director.

some instances the casing must be perforated after it has been inserted into the well. This calls for great care, in order to secure the maximum possible freedom of flow. Sometimes the casing has been so badly damaged by faulty perforating work that it has been necessary to redrill the well, at great expense, in other cases casing that was supposed to have been perforated has been found to be merely dented. A really satisfactory job requires the use of proper tools and considerable skill; details as to these tools and their use are given in Technical Paper 247 of the Bureau of Mines. Shop-perforated pipe is better wherever conditions permit its use. When the flow brings in much sand it is better to use screen pipe, which, though more expensive, is able to keep out the sand by means of its fine perforations. The size of the screen depends on the conditions to be met, as an economic balance must be struck between the amount of sand that may be handled and the resistance to free flow. A number of commercial types of screens are described in the paper mentioned above, and the effect of underground waters on these screens is discussed. When mud-laden fluid has been used in drilling, it is necessary to wash the mud out of the well before finally setting the casing. The details of procedure in carrying out this operation are given in the publication mentioned.

EVAPORATION OF CRUDE PETROLEUM.

By J. H. Wiggins.

THE evaporation of the volatile portions of crude petroleum causes the most serious loss to which it is subjected after it issues from the ground. The portion which thus escapes is not only the gasoline, but is the lighter, more valuable fraction of the gasoline, which is three times as valuable as an equal volume of the crude. An investigation made in the Mid-Continent field indicates that the yearly loss from this source amounts to 3 per cent. of the total amount of gasoline produced in the United States with an estimated value of over $25,000,000. Two-thirds to four-fifths of this loss can be prevented by protecting oil from free contact with air. The procedure to be followed and equipment needed to prevent exposure of the crude to the air varies according to the conditions existing at an individual well, and each operator of a lease or pipe line needs to study his individual problem.

MINOR NOTES.

Single Shot Blasting Unit.—An approval has been issued covering the first single-shot blasting unit to be approved under Schedule 12. The unit employs the Edison mine lamp battery, with special top and receptacle plug. The top and plug are arranged to prevent premature or accidental shots. The unit is approved for shot-firing only, and not for combination use.

Recovery of Gasoline from Still Vapors.—The Bartlesville station has completed an experimental refining plant and is studying methods of recovering gasoline from the still vapors.

Gas Masks.—The gas mask laboratory of the Pittsburgh station has begun experiments to develop a universal gas mask canister with all dry absorbents, sodium hydroxide to be used for the alkali. A tentative design for the canister has been completed. It will contain the following all-dry absorbents: (1) Charcoal, 700 c.c.; (2) cotton filter; (3) caustic pumice, 300 c.c.; (4) cotton filter; (5) hopcalite, 250 c.c.; (6) cooler; (7) silica gel. From preliminary tests of these substances, life against various gases is expected as follows: 3 per cent. CO, 60 minutes; 2 per cent. ammonia, 27½ minutes; 1 per cent. gasoline or other organic vapors, 17½ minutes; ½ per cent. chlorine, 35 minutes; ½ per cent. hydrogen cyanide, 194 minutes; ½ per cent. SO_2, 51 minutes; ½ per cent. phosgene, 42 minutes. Smoke, good protection.

Non-corrosive Priming Compositions.—Preliminary tests on non-corrosive priming compositions made at the Pittsburgh Station are now completed. It is expected to continue these tests in coöperation with some explosives manufacturing company. The best results were obtained with a mixture of fulminate, lead picrate, barium nitrate, and antimony sulphide. Three mixtures were prepared and tested, the one containing sufficient nitrate to oxidize all the carbon to carbon dioxide fired 80 rounds without missing. Mixtures with insufficient nitrate gave about 50 per cent. misfires. TNT and lead azide were found to be too insensitive to replace the fulminate.

Revival of the natural indigo industry in Bengal is described by HENRY E. ARMSTRONG (*Chemical Trade Journal and Chemical Engineer,* 1920, lxvi, 496). The eastern market will absorb the entire Indian output for years to come. The planters are devoting 2 per cent. of the sum realized on sales to research and propaganda. The decline in fertility of the indigo estates is being overcome by use of phosphate fertilizers. Extraction of the plants in cement vats may decrease the yield, for the Portland cement may give up lime to the steeping water and render it alkaline, while the microörganisms concerned in the liberation of the dyestuff from the plant are highly sensitive to alkali. The natural paste is far superior to the synthetic indigotin as a dye; with unspun wool, 6.5 parts of natural paste are equal to 8 parts of synthetic indigotin in dyeing heavy shades. Tests of a strictly scientific character made with piece goods on a practical scale show the natural product to be from 5 to 20, on the average 12.5, per cent. superior to the synthetic article. This superiority is ascribed to the presence in the natural product of other active constituents in addition to the blue indigotin which is the sole constituent of the synthetic product.

J. S. H.

Heavy Oil as Fuel for Locomotives. (*Le Génie Civile,* April 3, 1920.)—Before the war there was little interest in France in this use of oil except for the navy, but the destruction of the French coal mines by the Huns and their subsequent failure to deliver to France the promised quantities of coal have turned the attention of French engineers to the employment of oil-burning engines. The P. L. M. railway system took up the matter last October. The preliminary experiments gave favorable results, especially as regards the saving of time in getting up steam. In addition, this type of fuel showed itself well adapted for use on locomotives where there was an engineer alone without a fireman. Plans are now being carried out for the fitting of 225 locomotives with appliances for the burning of oil. This will be done both for shifting engines and for those used on long hauls.

G. F. S.

Fumigation with Formaldehyde.—D. W. HORN. (*Proc. Delaware County Institute of Science,* 1920) decides, after an elaborate investigation into the methods and efficiency of common forms of formaldehyde disinfection, that the bleach-chlorine method is the most generally applicable and is satisfactory. In carrying it out, the bleaching powder is simply placed in a bucket and the formaldehyde solution poured on it. For each 1000 cubic feet of space to be disinfected, 620 grams (one and one-third pounds) of bleaching powder and 800 c.c. (1.7 pints) of formalin should be used.

H. L.

THE FRANKLIN INSTITUTE.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of the Stated Meeting held Wednesday, June 2, 1920.)

HALL OF THE INSTITUTE,

PHILADELPHIA, June 2, 1920.

MR. CHARLES PENROSE *in the Chair.*

The following report was presented for final action:

No. 2748: Bullard Mult-Au-Matic. Howard N. Potts Medal awarded to Edward Payson Bullard, Jr., of Bridgeport, Conn.

The following reports were presented for first reading:

No. 2739: Vacuum Cleaner.

No. 2759: Screw Thread Comparator. Mr. R. W. Porter, a representative of the Jones & Lamson Company, was present and gave a demonstration of the Screw Thread Comparator.

R. B. OWENS,
Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, June 9, 1920.)

RESIDENT.

MR. CYRUS H. K. CURTIS, Publisher, *Public Ledger*, Philadelphia, Pennsylvania.

MR. HOWARD W. ELKINTON, Assistant Manager, Foreign Department, Philadelphia Quartz Company, 121 South 3rd Street, Philadelphia, Pennsylvania.

MR. CLARENCE P. FOWLER, Consulting Engineer, P. O. Box 27, Narberth, Pennsylvania.

MR. JOHN H. HIGGINS, Engineer of Tests, Camden Forge Company, Camden, New Jersey.

MR. JOSHUA R. H. POTTS, Lawyer, 929 Chestnut Street, Philadelphia, Pennsylvania.

CHANGES OF ADDRESS.

MR. E. S. BALCH, 1634 Spruce Street, Philadelphia, Pennsylvania.

CAPTAIN HENRY M. ELLIOTT, 352 State Street, Albany, New York.

MR. W. H. FINLEY, 412 North Washington Street, Wheaton, Illinois.

MR. W. M. GRAHAM, 113 North 19th Street, Philadelphia, Pennsylvania.

MR. W. C. A. HENRY, Room 1106, Syndicate Trust Building, St. Louis, Missouri.

MISS EMILY E. HOWSON, Glen Moore, Chester County, Pennsylvania.
MR. JONATHAN JONES, Resident Manager, McClintic-Marshall Products Company, Jamshedpur, via Tatanagar & B. N. Ry., Bengal, India.
MR. MARSHALL S. MORGAN, Fidelity Trust Company, 325 Chestnut Street, Philadelphia, Pennsylvania.
MR. TINIUS OLSEN, 500 North 12th Street, Philadelphia, Pennsylvania.
MR. G. L. PECK, Vice-President, Pennsylvania System, Personnel Department, Broad Street Station, Philadelphia, Pennsylvania.
DR. W. F. RITTMAN, 318 Locust Street, Edgewood Park, Pennsylvania.
MR. W. N. RUMELY, 3020 Sheridan Road, Chicago, Illinois.
MR. HORACE B. SMITH, Garfield Street, West Point, Virginia.
MR. P. F. SMITH, JR., Works Manager, Altoona Works, Pennsylvania System, Altoona, Pennsylvania.
MR. ALAN WOOD, 3RD, Flat Rock, North Carolina.

NECROLOGY.

James Gayley was born at Lock Haven, Pa., on October 11, 1855. He was educated at the West Nottingham Academy, West Nottingham, Md., later entering Lafayette College, where he devoted himself to the study of mining engineering, and was graduated in 1876. The first three years of his professional life were spent as a chemist with the Crane Iron Company. He then became superintendent of the Missouri Furnace Company, in St. Louis, and later managed the blast furnace of E. & G. Brooke Iron Company, of Birdsboro, Pa. In 1885 he was put in charge of the Edgar Thomson Steel Works, at Braddock, Pa., and later promoted to the office of manager of the entire Edgar Thomson plant. In 1897 he became a managing director of the Carnegie Steel Company. Mr. Gayley was the first to use charging bins for the raw material at the blast furnaces and installed the first compound condensing engine for supplying air blast to a blast furnace. He made use of the first mechanical ore unloader at the ore dock of the Carnegie Steel Company, at Conneaut, Ohio, on Lake Erie, and designed a vessel adapted to the use of such unloaders. Mr. Gayley made many important contributions to the progress of the metallurgical industries. His most important invention was the dry air blast, for which he was awarded the Elliott Cresson Medal by the Institute in 1908. He was a member of the American Institute of Mining Engineers, the American Iron and Steel Institute and a number of other organizations, and presented many papers on the blast furnace and blast furnace development to the various societies with which he was connected. In 1912, the University of Pennsylvania and Lehigh University conferred upon him the honorary degree of Doctor of Science, and in 1913 he was awarded the Perkin Medal.

Mr. Gayley became a member of the Institute on April 13, 1913.

Mr. I. F. Stone, 550 Park Avenue, New York, N. Y.

LIBRARY NOTES.

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BOOK NOTICES.

A TEXT-BOOK OF INORGANIC CHEMISTRY. Edited by J. Newton Friend, D.Sc., Ph.D., F.I.C. Vol. ix, Part i, 343 pages, contents and index, 8vo. Philadelphia, J. B. Lippincott Company. Price, $6.00.

This volume is part of a series on inorganic chemistry, which, according to the published schedule, is to consist of twelve separate books, although by an enumeration of two as simply "parts," the numbering of the volumes is restricted to ten. This is a somewhat awkward method, but seems to be rather a favorite with English publishers.

The volume in hand is devoted to the three sets of triads of group viii of the usual periodic classification, but iron, on account of the extent and importance of its chemistry, is assigned to a second part. The subjects, therefore, in this volume are cobalt, nickel, and the platinum group. A summary is given of the general affiliations of the whole group viii, and also of the special affiliations of each of the triads. It is curious that in speaking of the resemblances between iron, cobalt, and nickel, special attention does not seem to be called to the magnetic character of them, though the fact that nickel and cobalt are attracted by the magnet is mentioned in the descriptions of their properties.

So far as the text at large is concerned, it is an elaborate and comprehensive review of the natural occurrence, extraction, properties of the elements and their compounds and many of their industrial applications. The extensive literature has been carefully and conscientiously examined, and many interesting facts discovered. Among these is the statement that alloys containing nickel and copper have been known and used for several thousand years, as a coin issued by a Bactrian king about 235 B. C. contains nearly one-quarter of its weight of nickel. It is also stated that the United States was the first modern nation to introduce a nickel alloy coinage. The date of this introduction is given as 1857, which was indeed that of the issue in quantity, but some small nickel one-

cent pieces bear date 1856, though they are now rather of numismatic than monetary interest.

The close analogies of nickel and cobalt extend through a long line of compounds, and as in the case of some of the other well-marked groups of elements, even the differences, by their peculiar contrasts are, in a sort of way, affiliations. Thus, nickel salts are usually green and cobalt salts red when hydrated, and, respectively, yellow and blue when anhydrous, and both these contrasting colors are complementary pairs. A striking exception in the properties of the two elements is found in the potassium nitrite double salts, potassium cobalt nitrite being so slightly soluble in water as to be available as means of determining potassium, while the corresponding nickel salt is quite soluble.

The mechanical execution of the book is excellent; clear type, good paper and correct printing. A large amount of information is given in the form of tables, which greatly increases the value of a work of this type. In the tabular statement of the composition of pure nickel and copper-nickel coins on page 100, the value of the United States coins is given as "5 paras and 5 centesimos," statements that seem to be typographical errors; if not, they are rather peculiar descriptions of our well-known "nickel."

HENRY LEFFMANN.

TREATISE ON GENERAL AND INDUSTRIAL INORGANIC CHEMISTRY. By Ettore Molinari. Second edition, translated from the 4th revised and amplified Italian edition, by Thomas H. Pope, B.Sc., F.I.C., A.C.G.I. XIX–858 pages, index, 328 illustrations and 2 phototype plates. Philadelphia, P. Blakiston's Son & Co. Price, $12 net.

The first edition of the English translation of this work found a ready sale, which is evidence of its merits, and an examination of the present issue shows that the high standard of the work is maintained. The translator seems to have done his work well, as the text does not show any Italian idioms.

Unlike most works on applied science, some space is devoted to a summary of the history of chemistry and over one hundred pages to explanations of the principles of science as now generally accepted, including a good deal on physical chemistry. So far as the history of the science is concerned, there is not much to commend. The subject is treated too briefly to permit of any satisfactory presentation of it. It is very unlikely that the chemists that use this book will care for the early stories, interesting as they may be to a few. The author goes even back of the Greek civilization, which is generally considered to mark the inception of modern science, and ascribes much higher value to Assyrian, Babylonian and Egyptian civilization than seems to be proved concerning them. He quotes without qualification a statement that oxygen and the composition of water were known many years before the work of Priestley and Lavoisier, but this statement rests upon a letter to *Chemical News* in 1887, in which a vague article is quoted from "old book on chemistry" (not

further identified), which book in turn quotes from the memoirs of the Academy of St. Petersburg. A claim as radical as this cannot be allowed to rest on such a questionable basis.

It is not, however, necessary to give more space to the discussion of minor questions, and the reviewer must turn to the body of the work; namely, the treatment of industrial processes; that is, the many procedures in industrial inorganic chemistry. Here there is great fulness of description, with abundant illustrations of the forms of apparatus. The classification is based mainly on the arrangement of the periodic system, now widely used, but some exceptions are made when special analogies seem to require them. For instance, the gases of zero valency are discussed in connection with nitrogen because they are regular ingredients of the atmosphere. A slight error is made in the note on the discovery of helium when it is stated that it was "discovered spectroscopically in the sun's chromosphere by N. Lockyer in 1867." It was really in 1868 that J. N. Lockyer observed a hitherto unrecognized and unassigned line in the spectrum of certain solar prominences. However, everyone seems to go astray on the history of helium. Doctor Molinari does not refer to the interesting recent application of helium as substitute for hydrogen in balloons and to the opportune discovery of it in considerable amount in the natural gas of some localities in the western part of the United States. But these facts have come too recently to general public knowledge to have been available when the pages were going through the press. It is now known, however, that at the time the armistice was signed, the United States had on the wharf at New Orleans, ready to ship to Europe, over seven hundred cylinders of compressed helium nearly pure for use in dirigibles. The present edition of Doctor Molinari's work will maintain the popularity that the first English edition secured and will be found of great use in the laboratory of both teaching and works chemists. The book is well printed on good paper and does credit to author, translator, printer and publisher.

HENRY LEFFMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS. Report No. 62. Effect of Altitude on Radiator Performance. Preprint from Fifth Annual Report. 13 pages, illustrations, quarto. Washington, Government Printing Office, 1920.

The paper discusses the effect on the performance of aircraft radiators of changes in atmospheric conditions at altitudes, and a method is developed for estimating the performance at altitudes from the performance at the ground and probable atmospheric conditions. Meteorological data are included from which atmospheric conditions at altitudes may be estimated, and the method is illustrated by application to two types of radiators. The degree to which a radiator should be shuttered at altitudes is considered briefly.

Report No. 64. Experimental Research on Air Propellers, III. Preprint from Fifth Annual Report. 35 pages, illustrations, plate, quarto. Washington, Government Printing Office, 1920.

This report presents the results of a series of tests in continuation of those previously reported in Nos. 14 and 30.

The tests covered in the present report include the following characteristics:

Four propellers of nominal pitch ratio 1.3, uniform pitch, straight face and with four combinations of form of blade and area.

Five propellers of nominal pitch ratios 0.5, 0.7, 0.9, 1.1, 1.3, all of uniform pitch, one area and blade form, and with the driving face made slightly convex by adding a crown of one-sixth the normal thickness of corresponding straight face sections.

Four propellers of nominal pitch ratio 0.7, uniform pitch, one blade form and area and four locations of the maximum thickness ordinate of blade section.

Three propellers of nominal pitch ratio 0.7, uniform pitch, one blade form and area and with three degrees of deformation of the leading edge through pushing forward by successive increments.

Through propellers distributed over the pitch ratios 0.5, 0.7, 0.9, 1.1, 1.3, all with one blade form and area, and with radially expanding pitch derived in each case on the assumption of a constant value of the angle of attack.

Several of the propellers of these series combine with those previously reported on to form more extended series with all characteristics constant except one, and that one varying by regular steps; others are intended to show, for a typical combination of other characteristics, the influence of some one feature; as, for example, the distortion of the leading edge, of the location of the maximum thickness ordinate of blade section.

The paper is accompanied by a brief description of a method of carrying on the tests, with a general discussion of the results with reference to the points most noticeably brought out by the various series formed, either by the models of the present report alone, or formed by them in conjunction with those covered by the earlier reports.

Report No. 70. Preliminary Report on Free Flight Tests. Preprint from Fifth Annual Report. 33 pages, illustrations, plates, quarto. Washington, Government Printing Office, 1920.

A report of the free flight tests conducted by the Committee to determine some of the characteristics of two full-sized JN4H airplanes. The maximum lift coefficient was found to be about 15 per cent. higher in free flight and came at about 4° larger angle of incidence than on the model, and it was possible by using full power to just reach the burble point in level flight. The machines in landing did not exceed an angle of about 12°, so that the landing speed deduced from the maximum lift coefficient of the model will in this case give the landing speed very closely. The maximum L/D of the machines was between 7 and 8, which is very near to that of the model. The velocity of the slip stream was determined for several motor speeds, and the results agreed well with theoretical values. The longitudinal stability, with locked and free controls, was investigated for a JN4H and also a DH4. While the former machine was found to be quite unstable, the DH4 was stable.

Report No. 72. Wind Tunnel Balances. Preprint from Fifth Annual Report. 40 pages, illustrations, plates, quarto. Washington, Government Printing Office, 1920.

This report is devoted to a detailed description, with numerous illustrations, of the balance designed for the wind tunnel at Langley Field. It treats of the sensitivity of the N.P.L. type of balance, the means provided for adjusting sensitivity and the effect on sensitivity of the rolling and yawing moments and cross-wind force which appear when the oscillations of the balance throw the plane of symmetry of the model out of line with the relative wind.

A discussion of the possible errors of the N.P.L. balance follows. Seventeen factors are listed, and the importance and the means of combatting each is discussed. Finally there are brief descriptions of four other types of balance (Eiffel, St. Cyr, Curtiss 2-axis, and Wright). The precision of each of these types and their most striking advantages and drawbacks are briefly discussed.

Report No. 74. Construction of Models for Tests in Wind Tunnels. Preprint from Fifth Annual Report. 18 pages, illustrations, plates, quarto. Washington, Government Printing Office, 1920.

This report contains a full description and discussion of the best methods to be employed in constructing models of aircraft and parts thereof for testing in wind tunnels. It includes material on the construction of model aerofoils, of fuselages, and of tail surfaces, and also on the types of models to be used for such special tests as those on pressure distribution. The amount of detail which it is desirable to include on a wind tunnel model is discussed, and the means of approximating the resistance of radiators and other appendages without constructing geometrically similar models are treated. In short, the report is a general handbook on the subject, and is designed to eliminate the difficulties which airplane designers often experience in obtaining models suitable for wind tunnel use.

Report No. 83. Wind Tunnel Studies in Aerodynamic Phenomena at High Speed. Preprint from Fifth Annual Report. 52 pages, illustrations, plates, quarto. Washington, Government Printing Office, 1920.

Experimental investigation of flow phenomena has heretofore been rather unsuccessful because of lack of adequate methods. The writers designed the McCook Field wind tunnel to investigate the scaling effect due to high velocities of propeller aerofoils. During the course of the experiments, however, it was found possible to visualize the air flow by the following method: The velocities of the air flow discovered by the writers offers a solution to one of the fundamental problems of aerodynamics. This problem is the quantitative empirical measurement of the phenomena of fluid dynamics pertaining to flight and air flow. The method described in the report for visualizing air flow depends upon the fact that the moisture in the air condenses as a fog when the temperature is reduced to the dew point, provided that there is a solid or liquid nucleus to start the condensation. In the McCook Field wind tunnel the temperature drop is brought about through expansion of the air during accelera-

tion, due to a drop of pressure of 100 inches of water. The relative humidity of the atmosphere can be artificially raised if too low, and the necessary nucleus for condensation is provided by the model tested. Flow vortices become readily visible, and the report contains many photographs showing the air flow past an aerofoil under different conditions.

Copies of the above reports may be obtained upon request from the Committee.

R.

PUBLICATIONS RECEIVED.

National Advisory Committee on Aeronautics: Technical Notes. No. 1. Notes on Longitudinal Stability and Balance, by E. P. Warner. 13 pages, diagrams. No. 2. Airplane Performance as Influenced by the Use of a Supercharged Engine, by George de Bothezat. 7 pages, diagram. No. 3. Notes on the Theory of the Accelerometer, by E. P. Warner. 13 pages. No. 4. The Problem of the Helicopter, by E. P. Warner. 18 pages, diagrams. 4 pamphlets, quarto. Washington, 1920.

U. S. Bureau of Mines: Bulletin 196, Coal-mine Fatalities in the United States, 1919, by Albert H. Fay. 86 pages. Monthly Statement of Coal-mine Fatalities in the United States, March, 1920, by W. W. Adams. 8 pages. Technical paper 227, The Determination of Mercury, by C. M. Bouton and L. H. Duschak. 44 pages, illustrations, plate. Technical paper 243, Development of Liquid Oxygen Explosives During the War, by George S. Rice. 46 pages, illustrations, plate. Technical paper 245, Quarry Accidents in the United States During the Calendar Year 1918, by Albert H. Fay. 51 pages. Technical paper 247, Perforated Casing and Screen Pipe in Oil Wells, by E. W. Wagy. 48 pages, illustrations, plates. 6 pamphlets, 8vo. Washington, Government Printing Office, 1920.

Appreciation of Industrial Scientific Research. (*Electrician*, May 7, 1920.)—In commenting upon Gherardi and Jewett's paper on Telephone Repeaters, recently read before the American Institute of Electrical Engineers, the following comment is made: "American enterprise has, ever since the inception of commercial telephony, been largely responsible for the commercial development of the many features contributing to the modern telephone art as practised throughout the world; and the development and application of the thermionic telephone repeater to commercial service is no exception to this rule. The early years of the war period have hindred development in this country to an extent which is hardly realized in America, but in spite of this it is hardly possible to doubt that American appreciation of industrial scientific researches compared with the British attitude toward the same subject has been a very great factor in determining America's present leading position in telephony."

G. F. S.

CURRENT TOPICS.

Determination of Methyl Alcohol.—The detection and determination of methyl alcohol have become important problems in analysis of late years, owing to its use as an adulterant and substitute for ethyl alcohol and its poisonous qualities. S. B. SCHRYVER and C. C. WOOD (*Analyst*, 1920, vol. xlv, 164) describe a process depending on the oxidation of the alcohol to formaldehyde and the determination of this by a special colorimetric method. The general outline of the procedures are as follows:

For the determination of methyl alcohol in water alone samples of 5 c.c. each of the solution are placed in test-tubes about 15 cm. by 2 cm., and 5 c.c. of solution of ammonium persulphate solution of differing concentrations added successively. The persulphate solutions are made up in known concentration graduated by some simple ratio. The tubes are heated in boiling water for ten minutes, when 1 c.c. is withdrawn from each tube by a pipette, placed in a series of tubes, each of which contains 1 c.c. of 1 per cent. of phenylhydrazin hydrochloride, to which mixtures are then added 1 c.c. of a 2.5 per cent. solution of potassium ferricyanide and 3 c.c. of concentrated hydrochloric acid. It will be found usually that the concentration of the methyl alcohol will lie between two limits, namely, one in which the amount is such that the persulphate is sufficient to oxidize completely the formaldehyde first formed, and a limit in which some of the liquid still gives a reaction for formaldehyde after the heating. A second series of experiments can then be carried out in which the persulphate is used in strengths ranging between the limits ascertained. The mixtures can be adapted to the degree of accuracy desired. For each concentration of methyl alcohol there corresponds a definite concentration of persulphate just sufficient under the conditions of the experiment to oxidize all the formaldehyde formed in the reaction. A considerable number of test analyses are given.

An attempt to determine methyl alcohol in the presence of ethyl alcohol by the above method failed, and the following modification was made:

Ten c.c. of ethyl alcohol, containing methyl alcohol, are diluted with 50 c.c. of water, 5 c.c. of this mixed with 5 c.c. of a 1 per cent. solution of the persulphate, and heated for ten minutes in a test-tube provided with a short air condenser. One c.c. of this mixture is added to 1 c.c. of a 1 per cent. solution of phenylhydrazin hydrochloride and heated in boiling water for five minutes. When cold, 1 c.c. of a 2.5 per cent. solution of potassium ferricyanide and 3 c.c. of concentrated hydrochloric acid are added. A pink liquid is

produced if methyl alcohol was present, which can be compared with tints produced by the same process from samples containing known amounts of the two alcohols. A colorimeter will give better results. Test analyses show that the method is accurate to about 1 per cent. when the amount of methyl alcohol present ranges from 0.5 to 5.0 per cent. For more accurate results the pink solution may be diluted with 70 c.c. of water and compared with standards of known composition. The commercial sample of ethyl alcohol used in the experiment, gave a slight formaldehyde reaction when treated in the manner described, but it is impossible to say whether this is due to the presence of impurities or to the slight production of formaldehyde from the ethyl alcohol itself.

A slight modification of the method has been found satisfactory in the determination of methyl alcohol in acetone.

H. L.

The Crystallography of Snow. E. T. WHERRY. (*Monthly Weath. Rev.*, 1920, vol. xlviii, 29.)—The beauty and almost endless variety of forms of snow crystals have been matters of interest for many years, but only very few studies have been made from the purely scientific point of view. Doctor Wherry's paper presents a consideration of the forms from the point of view of the crystallographer. Previous investigators have shown that snow and ice crystals are assignable to the trigonal system (sometimes termed the trigonal subsystem of the hexagonal system), and these forms have been found to be different at opposite ends, frequently enough to place them in the hemimorphic class of the system. Ice does not rotate the plane of polarized light, which shows that it belongs to the particular class known as trigonal-pyramidal, of which tourmalin is the best-known example.

The trigonal system is characterized by the presence of two kinds of axes, three of one and one of the other. The three similar axes lie in the same plane crossing each other at angles of 60°; the other, called for convenience, the unique axis, is perpendicular to this plane. In this class the opposite ends of the unique axis are crystallographically unlike, but snow crystals are usually so developed that this feature is obscured, though occasionally it is developed in striking manner. The nucleus from which a snow crystal starts, probably consists of a single molecule of ice, which contains three molecules of H_2O. As new material attaches to this the results will differ according to the rate of accretion. If the growth is very slow, the crystal may retain the form throughout, but with rapid growth the crystals become elongated and needle-like, and when the growth occurs in several directions around an axis of symmetry, a skeleton of a possible solid form will be produced.

The paper is illustrated with numerous figures mainly from a paper by Shedd (*Monthly Weath. Rev.*, 1919, vol. xlvii, 691) and taken by W. A. Bentley. H. L.

Production of Synthetic Camphor in the United States. (*A. C. S. News Service.*)—The great demand for camphor in the manufacture of celluloid and also for medicinal use, coupled with the present restrictions by the Japanese government on the exportation of the natural product has stimulated the manufacture of the substance from spirits of turpentine.

Although in popular usage the term "camphor" is applied to a substance which is derived from an aromatic tree grown largely in Japan, Formosa and China, there are several other kinds. Camphors are mostly crystalline solids obtained from plants. Technically, they are volatile, oxygenated hydrocarbons, possessing a peculiar odor, and can be prepared artificially by chemical processes.

It has been known for years that a grade of camphor closely resembling the Japanese variety could be made from spirits of turpentine. It has only been recently, however, owing to commercial conditions, that the manufacture of synthetic camphor was instituted on a large scale. As approximately nine-tenths of all the turpentine produced in the world is distilled in the United States, chemists believe that the manufacture of American camphor will develop into a large industry. As a result of the World War and of the high cost of labor, spirits of turpentine is quoted at $2 a gallon, or about four times its price in *ante bellum* days. Although it is improbable that turpentine can ever be made profitably at the old figure, it may decrease in price sufficiently to give the American camphor factories a good safe margin on which to fight the Japanese trade. Even if the manufacturing chemists of the United States are unable to much undersell the Japanese product now, they should be in a position to counteract the monopoly of Nippon and improve the market. Those desirous of fostering the chemical independence of the United States declare that the founding of an American camphor industry is in line with the effort to make this country independent of the German cartels, which for years dominated the dye trade of the world.

Jelly.—According to C. H. CAMPBELL (*Journal of Industrial and Engineering Chemistry*, 1920, xii, 558–559), acid, pectin, and sugar must be present in the proper proportions in order to obtain a good jelly. A delicate quality, resembling that of home-made jelly, is imparted by a pectin content of 0.75 to 1.0 per cent., while 1.25 per cent. pectin produces a fine commercial jelly. The acidity, calculated as sulphuric acid, must lie between 0.27 and 0.50 per cent.; an acidity of 0.3 per cent. is necessary to produce a jelly of good quality. An excess of sugar produces a soft jelly, an insufficient amount of sugar a tough product. The yield of jelly becomes greater as the amount of sugar used increases. The actual yield (volume) of jelly does not depend on the pectin content. J. S. H.

Zinc and Copper, Regular Constituents of the Human Body.—According to E. ROST (*Die Umschau*, 1920, xxiv, 201–202), zinc and copper occur in the human body; the amount of zinc, calculated as millegrams of metal per kilogram of organ, was: Liver, 52 to 146; muscle, 47 to 52; brain, 11; copper was also present, but in lesser amount. Zinc enters the body with the food, and is derived directly or indirectly from the soil, or from water which has flowed through galvanized iron pipes. The zinc content of various foodstuffs (milligrams of zinc per kilogram of food) was: Beef, veal, pork, mutton, and horse meat, 26 to 50; beef liver as high as 83; horse liver as high as 339; sea fish, 4; hens' eggs, 9.8 (equal to 0.5 milligram zinc per egg); bread, 5 to 8; potatoes, 2.3; dried vegetables, 6.13. The amount of zinc present in each litre of milk was: Cows' milk, 3.9; goats' milk, 2.3; human milk, 1.3. Swiss cheese, beet sugar, and beer did not contain zinc. Copper was present in smaller amounts in the meat and the liver, though one beef liver contained 119 milligrams of copper per kilogram of organ. Both zinc and copper are regular though accidental constituents of the organism—human, animal, and plant—under present conditions. The quantity of these elements normally present in the food is unavoidable, and does not injure either the digestive organs or any other part of the body. However, if vessels either made of, or coated with, zinc be used for cooking or storage of foods which are acid or may become acid, then the food may contain zinc salts to such an extent that injurious effects may be produced on the system.

J. S. H.

Dehydration is discussed in a paper by SAMUEL C. PRESCOTT on "Dried Vegetables for Army Use" in the *American Journal of Physiology*, 1919, xlix, 573–577. In the process of dehydration, water is rapidly removed from vegetables, fruits, and other foods through evaporation by air currents or vacuum combined with moderate heat. The cellular structure should be unchanged. When cooked, dehydrated foods return approximately to the bulk and character before drying, and have the color, flavor, and texture of cooked fresh material. By dehydration a food may be reduced as much as 90 per cent. in weight and as much as 50 per cent. in bulk; the product is more easily transported and keeps well for a long period of time. During the war approximately 40,000 tons of dehydrated vegetables were shipped overseas to the United States forces. Experiments on guinea-pigs have shown that a ration composed entirely of dried vegetables of non-acid character contains little, if any, of the antiscorbutic substances, while a ration composed of dry fruits of an acid character, such as tomatoes, oranges, and lemons, does not produce scurvy even on long-continued feeding.

J. S. H.

The Otophone: an Instrument for Reading by Ear. E. E. FOURNIER D'ALBE. (*Nature*, May 6, 1920.)—By a series of lenses the image of a straight incandescent lamp filament is thrown on a sheet of paper. Between the filament and the lenses is interposed a disk whose radius is parallel to the filament. The disk is pierced with five concentric sets of square holes, the innermost 24 in number and the outermost 42. The disk transforms the line image of the filament into a series of points. The disk revolves thirty times per second. Thus there are from 1260 to 720 interruptions of the light per second. Let a selenium cell be placed near the flickering row of dots. From each of these light is diffusely reflected to the selenium, whose electrical resistance is thereby changed. If the selenium is joined in series with an electric cell and a high resistance telephone receiver, a note will be emitted by this which is compounded of the tone caused by the five intermittently illuminated spots of light. Take the spot nearest the centre of the disk. Seven hundred and twenty times per second the light is cut off from it and the same number of times the resistance of the selenium varies and just as often the current strength varies and the diaphragm of the receiver will move with each change of current. Hitherto it has been assumed that all the spots of light fall on white paper. Let one, however, fall on a part of the paper covered with black ink. From this no light will be diffusely reflected to the selenium and the compound note from the receiver will lack the tone corresponding to the frequency of this spot.

In the use of this instrument by the blind the group of five spots of light is made to travel along a line of print. The note changes with the number of spots falling upon the print. Each letter has a complex of sound characteristic to itself. One blind girl reads habitually at the rate of 25 words per minute.

G. F. S.

Effect of Changes of Pressure on a Galvanic Cell. W. M. COLEMAN. (*Proc. Phys. Soc., London*, vol. xxxi, p. 57.)—An increase of pressure of 240 mm. of mercury caused the current coming from a cell to increase by 5 milliamperes, or about 12 per cent., while a decrease of the same extent was followed by a similar decrease of current. These changes were observed when the pressure varied rapidly. They rarely followed slow changes of pressure.

Again, a long cell two metres from end to end was examined first with one end down then with the other. When the cell was horizontal the current was 4 milliamperes; when the zinc end was down the current was six of the same units. Upon putting the copper end down the current grew less.

The author explains these effects by changes of polarization due to dislodgement of gas.

G. F. S.

Eka-cesium.—According to the periodic law, an element, as yet undiscovered, probably exists, and belongs beneath cesium in the group of the alkali metals or group I. This element is tentatively designated eka-cesium. L. M. DENNIS and R. W. G. WYCKOFF of Cornell University have made "A Search for an Alkali Element of Higher Atomic Weight Than Cesium" (*Journal of the American Chemical Society*, 1920, xlii, 985–990). The raw material was 3500 grams of the very rare mineral pollucite, which is a silicate of aluminum and cesium and contains over 30 per cent. of cesium oxide. The mineral was decomposed by prolonged boiling with concentrated hydrochloric acid, and a solution of the alkali metals present in it was thus obtained. The alkalies were then subjected to fractionation (1) by precipitation of the chlorides with hydrogen chloride, (2) by solution of the perchlorates, (3) by crystallization of the sulphates, (4) by solution of the alums. "In these several processes those fractions in which the higher analogue of cesium, eka-cesium, might be expected to be concentrated were examined by means of the arc spectra of the solid material in the red, the visible, and the ultra-violet portions of the spectrum. In no case were there indications of the existence of eka-cesium."

J. S. H.

Relative Nutritive Value of Meat and Milk. (*Jour. Ind. Eng. Chem.*)—The Committee on Food and Nutrition (National Research Council) states as the result of recent investigations, that about 18 per cent. of the energy of grain fed to cattle is recovered for human consumption in milk, but only about 3.5 per cent. in beef. Similarly, crops on a given area will yield four or five times as much protein and energy when fed to dairy cows as when used for beef production. In providing mineral substances and vitamines, the milk of the cow contrasts even more favorably with the beef animal. The vitamines and calcium salts contained in hay and grain are stored in the muscular tissue only to a slight extent, but are in relative abundance in milk.

H. L.

The value of the synthetic mannitol olive oil as a food has been studied by WILLIAM D. HALLIBURTON, JACK C. DRUMMOND, and ROBERT K. CANNAN of King's College and the Cancer Hospital, London (*Biochemical Journal*, 1919, xiii, 301–305). The experimental animals were rats. Under similar conditions the utilization of the mannitol olive oil and of olive oil by the animals was practically the same, being 95.8 per cent. for the former and 96.6 per cent. for the latter. No toxic action followed the prolonged administration of the mannitol olive oil to rats as part of their ration.

J. S. H.

Photographing a Mirage.—In the *Proc. Roy. Soc. of Edinburgh* (1918–1919, vol. xxxviii, 166), A. C. RAMAGE gives an account of a mirage frequently observed on a public road in Scotland. The first observation was made on a day of bright sunshine, the appearance being of pools of water reflecting the foliage very vividly, and further down the road images of other pools. The road was perfectly dry at the time. The air over the road was vibrating, and the line of telegraph wires with white insulators seemed to be also vibrating. Walking towards the apparent pools they vanished, but on retracing steps again appeared. The paper describes in some detail the several appearances, which were noticed distinctly by other persons. The road at the point at which the phenomena occur is made up of bitumen and road-metal and is sheltered.

The most interesting fact about the observation is that the mirage has been photographed. A brief account of this result is given in a later issue of the proceedings (1919–1920, vol. xl, 33), in a communication by the General Secretary, who states that similar appearances have been reported from various sections of the country, and Mr. C. F. Quilter has obtained five excellent photographs, showing all the important features of the mirages. In one, taken in August, 1919, the shaded side of a telegraph pole with neighboring trees, and a white-walled house beyond were distinctly seen as if reflected from a pool in the middle of the road.

H. L.

Photo-synthesis.—BENJAMIN MOORE and T. ARTHUR WEBSTER (*Proceedings of the Royal Society of London*, 1920, xci, B, 201–215) have demonstrated that the unicellular fresh-water algæ can fix atmospheric nitrogen, grow, and synthesize protein in the absence of all other sources of nitrogen, provided an abundant supply of carbon dioxide be available. However, the oxides of nitrogen in the atmosphere are utilized more readily than the free element. These algæ are able to utilize formaldehyde and methyl alcohol as food and to produce marked growth when these compounds are the sole source of carbon; however, these compounds must be fed in sufficiently high dilution, otherwise they are poisonous to the living cell. This utilization of formaldehyde and methyl alcohol as food is of importance, for these compounds are the first products of photo-synthesis.

J. S. H.

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